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A ROWSE MUIR PUBLICATION

CONTROL

SYSTEMS · INSTRUMENTATION · DATA PROCESSING · ENGINEERING · APPLICATIONS

NOVEMBER 1960 VOLUME 3 NUMBER 29 MONTHLY 3/6

V3 29 NOV

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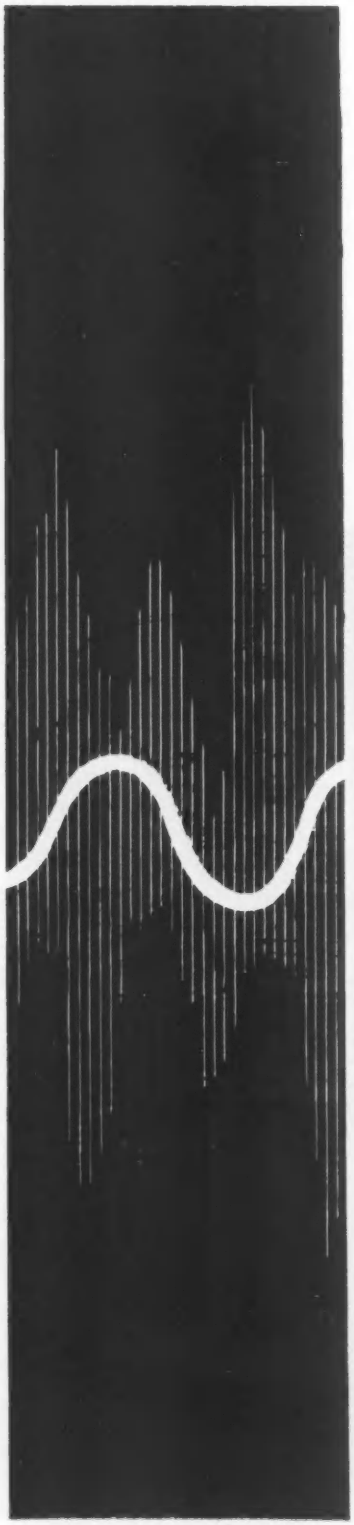

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CONTROL

SYSTEMS · INSTRUMENTATION · DATA PROCESSING · ENGINEERING · APPLICATIONS

VOL 3 NO 29 NOVEMBER 1960

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LOOKING FOR A JOB? Control *carries the best jobs going in instrument and control engineering.* **SEE PAGE 206 AND ONWARDS**

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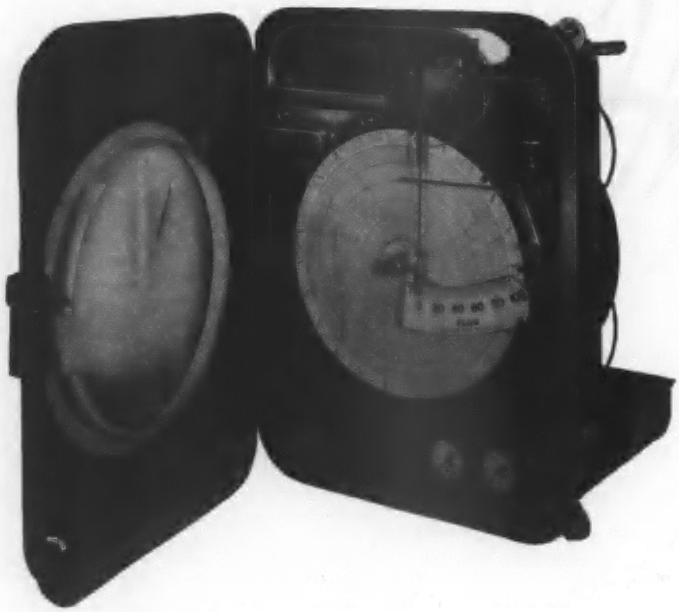

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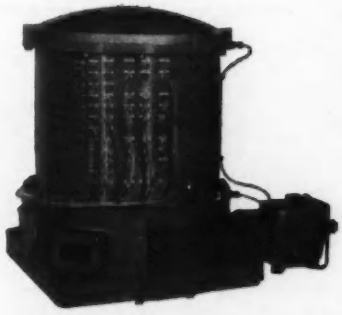
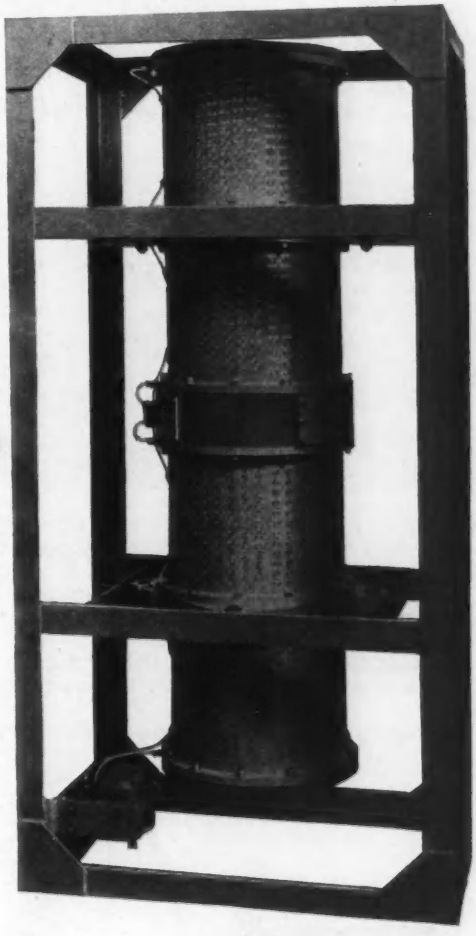


1 megabit to 4 megabits



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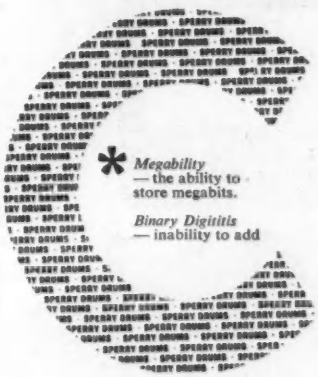

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Magnetic Storage Drums

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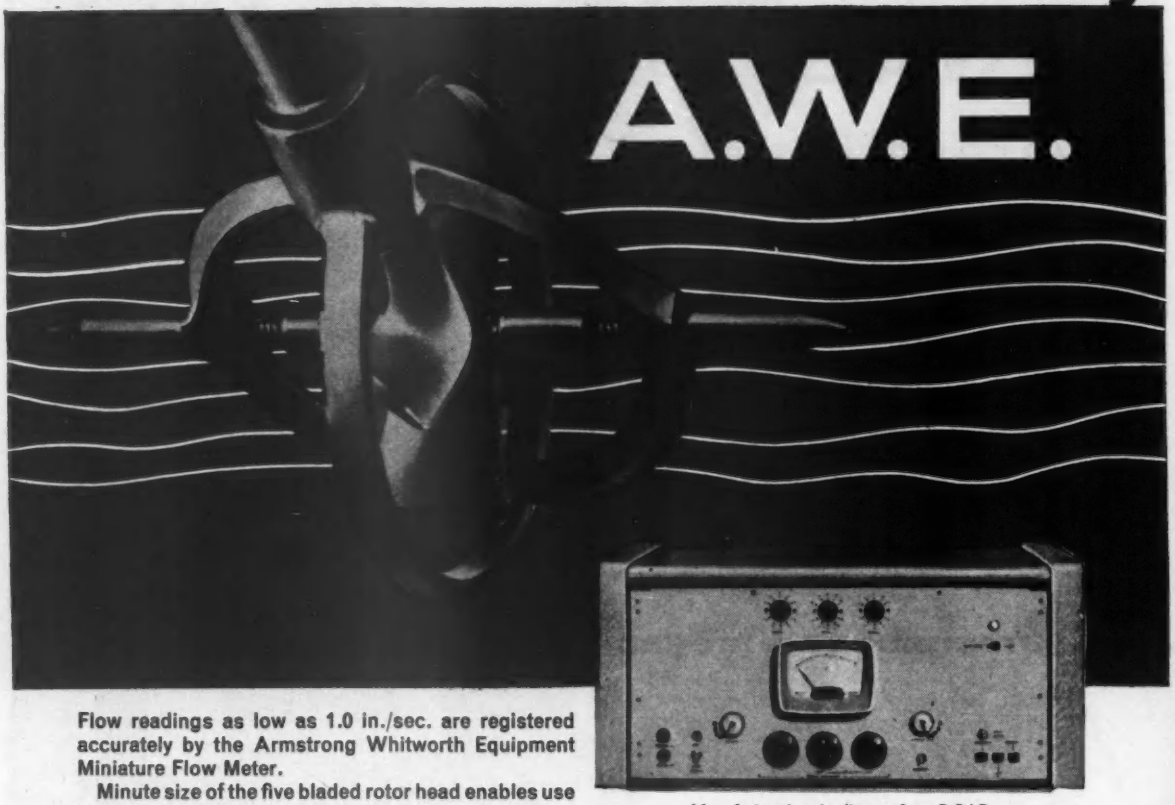

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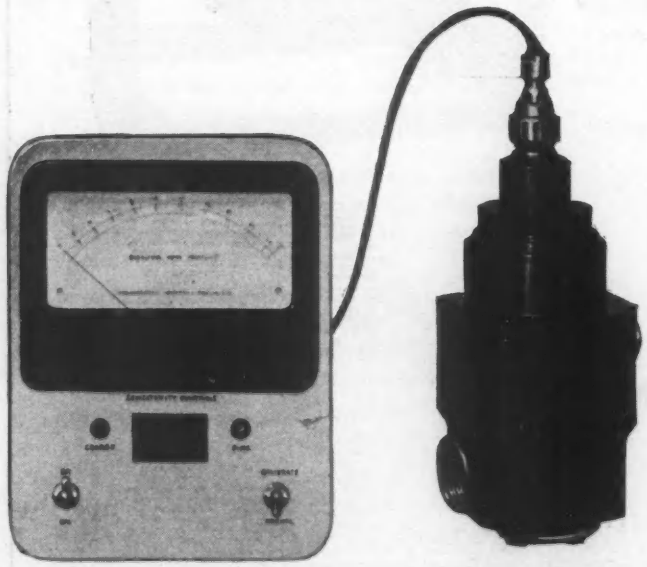

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- Computer read-out devices.
- Exit signs.

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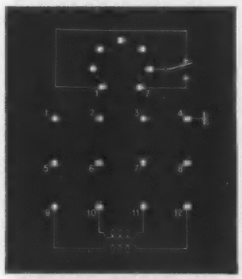

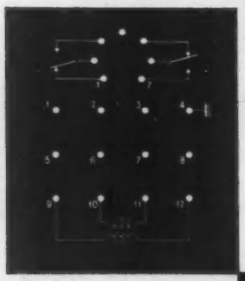

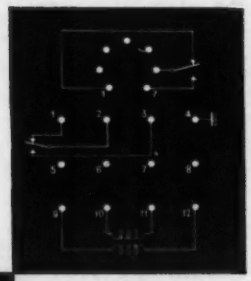

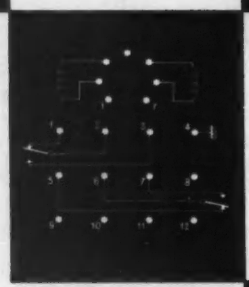

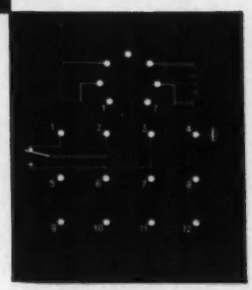

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14

FORD

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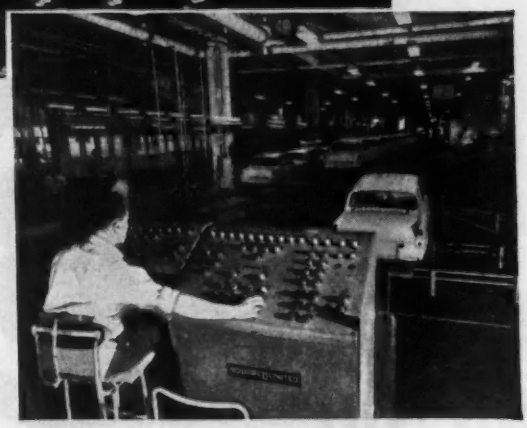
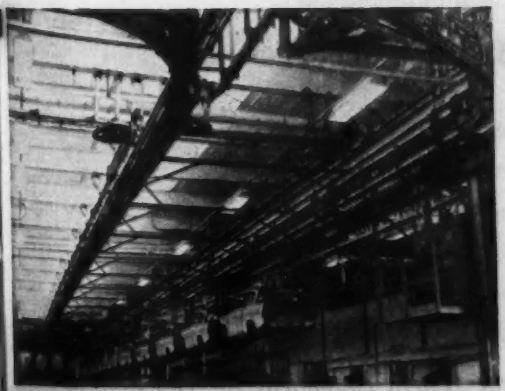


Local consoles sited throughout the plant supplement the two central control rooms. Here the transfer between primer and final enamel sections is supervised.



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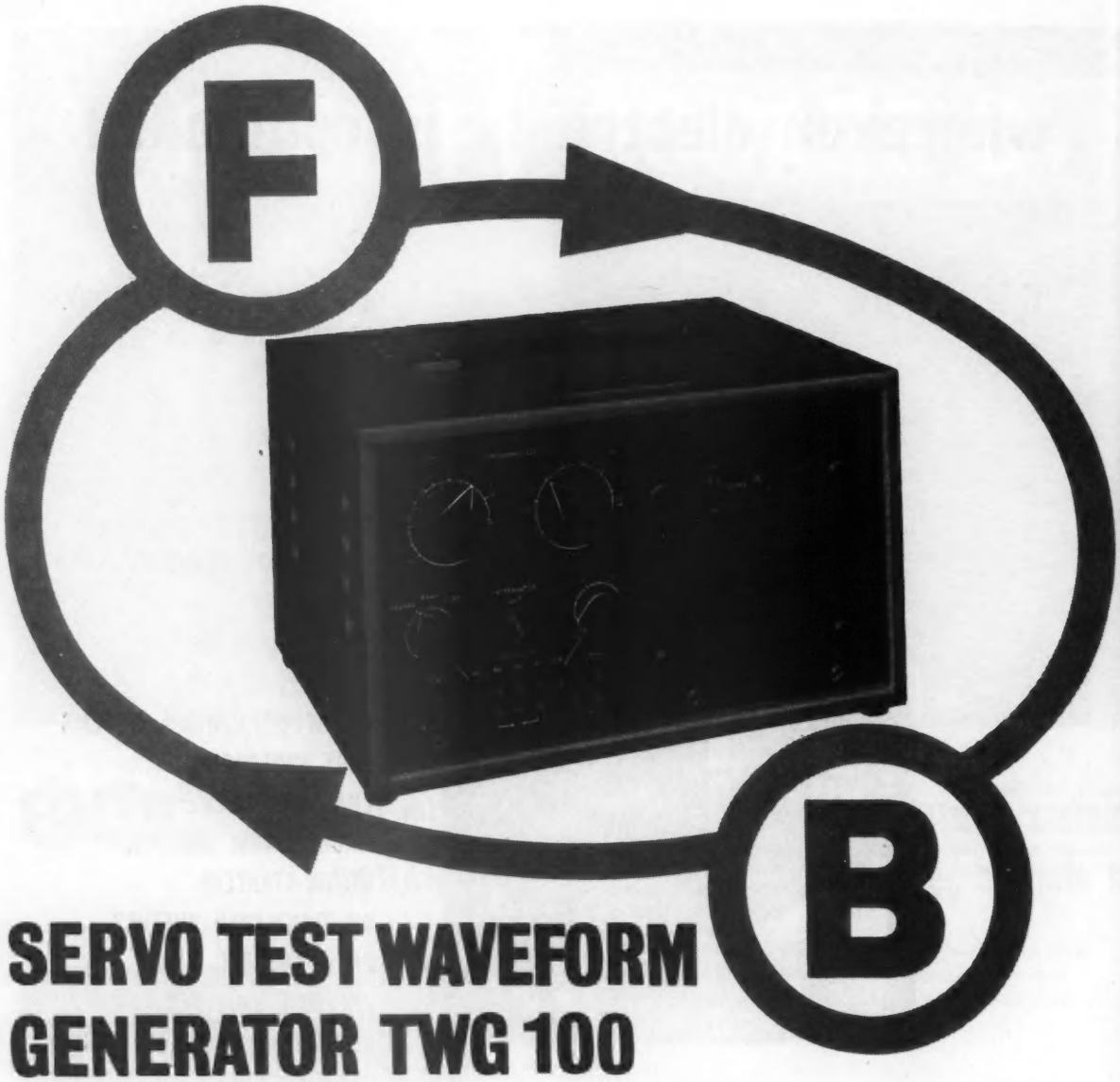

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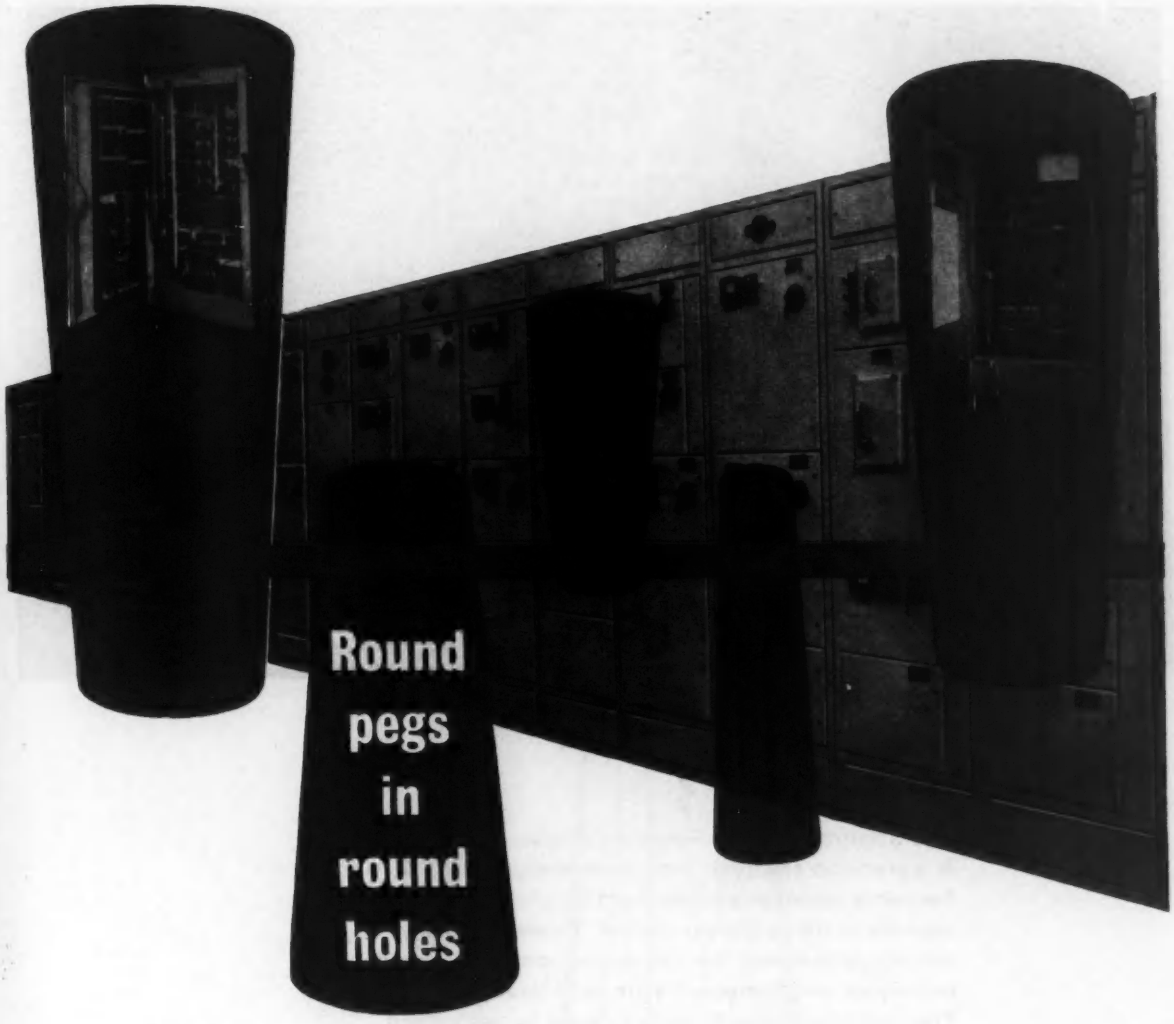

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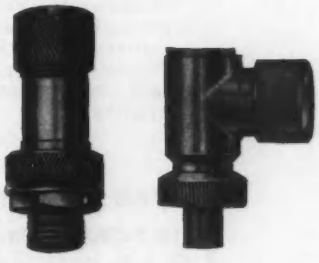

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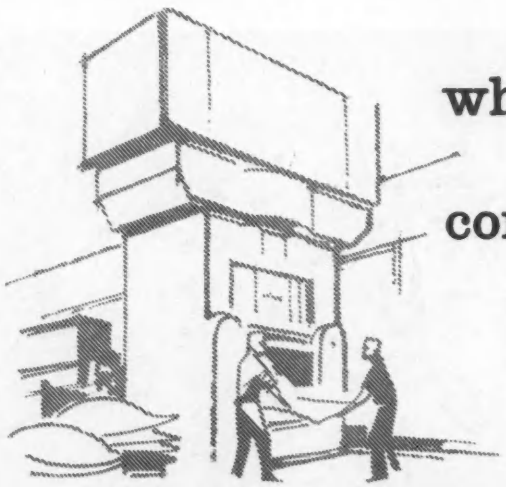

wherever rugged contactless control equipment is vital you'll need Sanders

STATIC SWITCHING SYSTEMS

The Proximity Switch will provide a signal to operate a Basic Logic Unit, whenever a mass of ferrous material comes within 5mm of the operating face. Having no moving parts, it is an encapsulated wound component suitable for use in conditions of vibration, shock, dust, damp—in fact, in any environment where the epoxy potting compound and the cable gland will not be damaged.

The Contactless Changeover Switch, a form of differential transformer, will provide signals to operate Basic Logic Units, changing over when the armature is rocked by about 1.5 degrees i.e. 1mm movement at one end. Apart from the solid steel armature which pivots on a stainless steel pin in a bronze bush, there are no moving parts; the body of the device being similar to that of the proximity switch.

The Basic Logic Unit provides the normal logic functions i.e. OR, AND, AND / NOT, LATCH etc. The standard inputs signal is 1.5 Volts at 68 ohm, although pre-amplifiers can be provided if required. An output of 900mW into 47 ohms is normal for the basic logic unit, sufficient to drive any Sanders transductor from 1 Watt output to 10kW output.
The latching units have a "MEMORY" facility enabling them to remain latched during total power failure.

This Static Switching System provides control equipment without the use of electrical contacts which may corrode, weld or wear out and with the minimum moving parts required to provide the initial information to the system. The only electrical components used in the entire system are encapsulated transductors, wirewound resistors, transformers and silicon rectifiers—components used well within the manufacturers' limits to ensure reliability.
The information fed to the basic logic units can be derived from photo-electric cells, tacho-generators and any device that will provide a few milliamps into a 100 ohm winding.

This is one of a series of new instruments and components by

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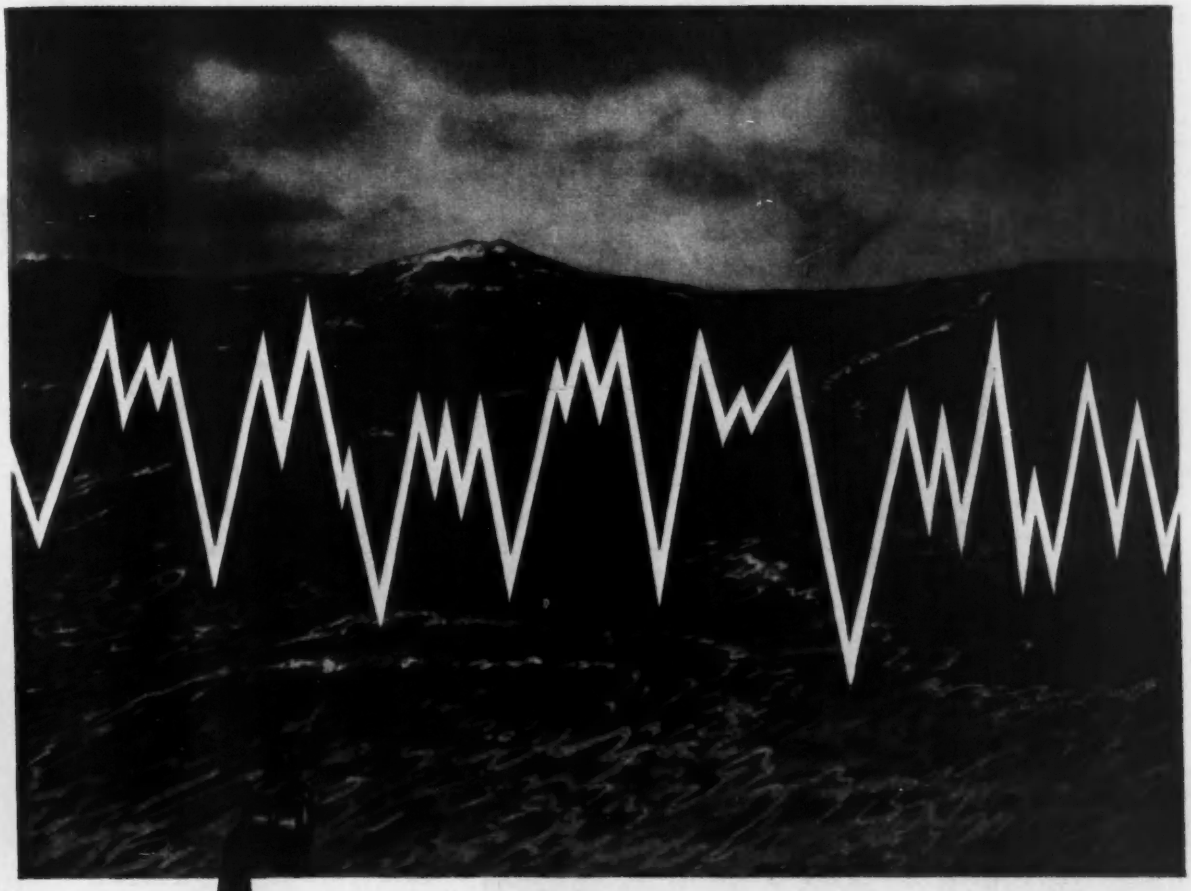

Telecommunications

Two recent major steps in the improvement of world telecommunications have been the laying of the first Trans-Atlantic and the California—Hawaii submarine telephone cables.

When laying cable either on a flat sea bed or over underwater mountain ranges, the exact control of paying out speed and tension in the cable is of paramount importance. 'VSG' variable delivery oil hydraulic pumps are used to act as brakes on the cable, which is drawn out of the ship by its own weight. This enables a very smooth and regulated control to be maintained or instantly varied to suit ship speed, paying out speed and tension in the cable.

It is just another of the highly varied applications of 'VSG' variable delivery pumps and transmission gears which have now been serving modern industry for over fifty years.

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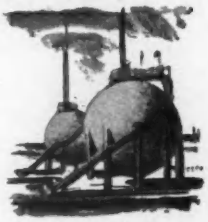
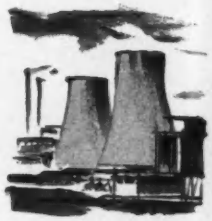
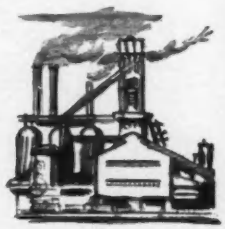
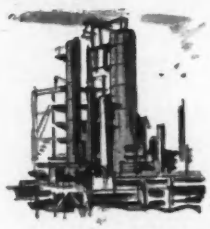
For the first time – a low-cost approach to computer control of processes







Up to 42 inputs plus internal pre-set constants. Up to 6 outputs capable of supplying ± 30 mA. Computing capability equivalent to 75 amplifiers plus 25 multipliers. Self-checking — fully transistorised for reliability — sealed case.



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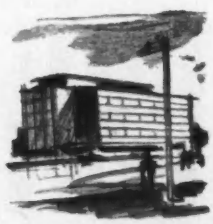
By a new concept of analogue computation, the many variables involved in a process can, at last, be united and co-related in an optimum relationship to improve quality, cost and output.

The low price of the computer, together with its compatibility with existing analogue measuring and actuating systems, facilitates progressive expansion of this form of control in a process plant.

System analysis and similation facilities are available to study the application of this computer to industrial problems.



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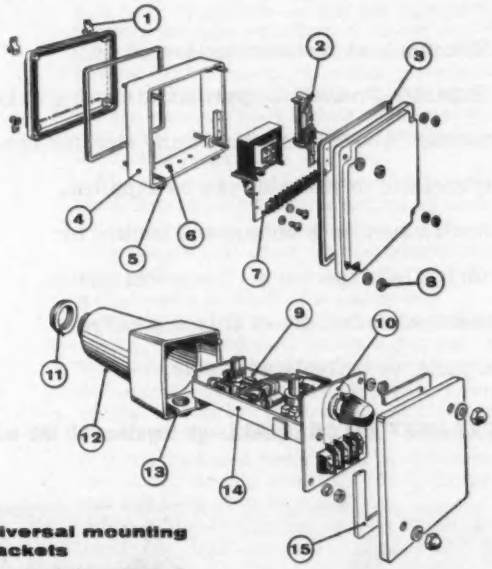

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7. Simple circuit
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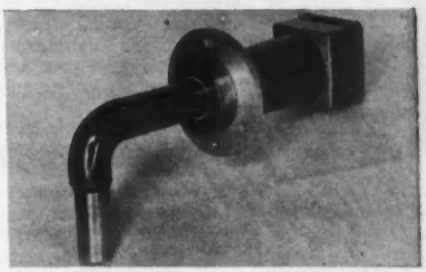
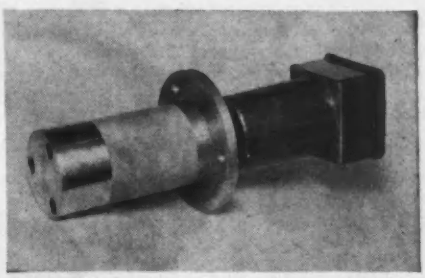
These simple rugged units—operated by the controlled material causing electrical capacitance change between the probe inserted through the wall of the container—are fully transistorised. Advanced design and production techniques make possible high performance and reliability at a lower price than ever before.



For adherent materials—glazed ceramic angle probe.



Heavy duty probe for coal, stone and similar materials.

Units are being used to indicate and control the level of, beer, bicarbonate of soda, brine, bonemeal, cashews, carbide, cement, cereals, chalk, chemicals, chocolate, clay, coal, coke, fertilizer, flour, flue-dust, fruit juices, glass marbles, glucose, gravel, hydrochloric acid, lime, malt, milk, oils, oily water, peas, peat, petrol, plaster, plastic granules, plastic powder, rubber, sand, salt, sawdust, seeds, sugar, water, wood chips, wood pulp.

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Electrical Aids in Industry — *Data Sheet* **No. 11**

Dielectric Heating - 2

The ability of dielectric heating to generate heat through the mass of a suitable material provides the following considerable advantages over other heating methods.

1 A body of uniform section and composition is raised in temperature uniformly throughout. Hence there is no waiting for heat to be transferred from an external heat source to the surface of the body and thence to its interior, and this is of particular advantage when the body is thick, and, as is often the case with dielectric materials, has poor heat-conducting properties.

2 The rate of heating of such bodies is, therefore, much faster than by external heating methods.

3 Since there is no external heat source, overheating or burning of the surface of a heat-sensitive material is avoided.

4 High thermal efficiency is achieved.

5 The amount of heat generated in the work is usually predictable and power input and heating time can be under positive control.

6 Production can start immediately after switching on and no current is used, nor heat lost, during periods of shut-down.

7 Vastly increased productivity is obtainable with less labour (usually unskilled), and fewer machines and less floor space are required.

8 Flexibility of layout makes it possible to plan the factory to best advantage, as dielectric heating equipment can usually be inserted directly into the production line.

Dielectric heating: typical application data

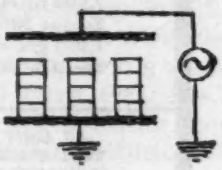
Typical application	Frequency	Radio frequency power
Thermoplastic welding.	20-100 Mc.p.s.	Up to 1 kW
Plastic pre-heating, wood glueing.	10-40 Mc.p.s.	2-30 kW
Plywood manufacture.	2-10 Mc.p.s.	Above 30 kW

Note: 1 Mc.p.s. = 1,000,000 cycles per second.

A few of the industrial applications of dielectric heating are briefly described below.

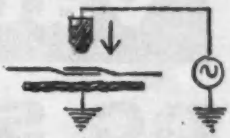
Preheating Thermosetting Plastics

Dielectric heating is the ideal way of preheating moulding powder pellets used in the production of thermosetting plastic mouldings, since these materials are generally poor heat conductors. Properly applied, dielectric preheating promotes faster curing and hence a shorter moulding time, often increasing production ten to fifteen times. There is a marked reduction in tool wear, and thicker sections can be moulded, as the material is plastic when placed in the mould. There is less damage to, and movement of, metal inserts.

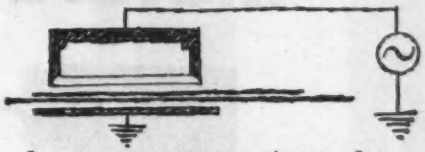


Welding of Thermoplastic Materials

An important and extensive application of dielectric heating in the plastic industry is the welding of thermoplastic sheets in the fabrication of such commonly used articles as raincoats, hoods, handbags, pouches and packaging materials. Dielectric heating is the only method which can usefully be employed since the heating electrodes, and hence the outside sheet surfaces remain cool while the inside surfaces forming the joint are fused, and a perfect weld results.



Two or more thermoplastic sheets are welded under pressure from electrodes suitably shaped to the area of weld required, the current being switched on at the same time as pressure is applied, and off as soon as the weld is completed and the pressure released. Stitching is thus eliminated and a far stronger joint achieved.



In most cases, component pieces are first cut from patterns and preliminary welding carried out to attach any fastening tabs and the like. The pieces are then brought together in a suitable loading frame and the main welding carried out to produce the complete article. In some cases, a suitably profiled electrode can be fitted with a knife edge to cut the sheets immediately outside the weld line, welding and pattern cutting being thereby carried out in the one operation. Dielectric welding can be applied also to very large thermoplastic products such as linings for swimming pools, and cinema screens.

Drying

Drying of materials by dielectric heating has the great advantage that the material tends to dry out from the centre, the reverse of what happens when external heating methods are employed, and the risk of overdrying and overheating of the surface is eliminated. In general ½ to 1 unit of electricity is required to drive off 1 lb. of moisture, depending upon the thermal properties of the material being dried. While the removal of large amounts of water from inexpensive commodities may sometimes be uneconomical, dielectric heating in the production line often leads to a higher overall production efficiency. It is valuable for removing final moisture traces and becomes increasingly economical as the value or heat-sensitivity of the commodity increases.

Rubber

External heating tends to dry and cure the surfaces of a thick latex mass before its centre, but dielectric heating properly applied promotes uniform conditions throughout.

Loaded rubber may not heat uniformly in a dielectric field due to uneven dispersion of its load, but nevertheless rubber preforms loaded up to about 15% are preheated dielectrically to reduce moulding times appreciably, the temperature evening out in the mould to give uniform curing.

Further examples are given in Data Sheet No. 12.

For further information get in touch with your Electricity Board or write direct to the Electrical Development Association, 2 Savoy Hill, London, W.C.2. Telephone: TEMple Bar 9434.

Excellent reference books on electricity and productivity (8/6 each, or 9/- post free) are available — "Induction and Dielectric Heating" is an example.

E.D.A. also have available on free loan in the United Kingdom a series of films on the industrial uses of electricity. Ask for a catalogue.

6774

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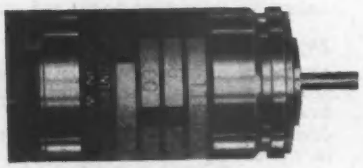

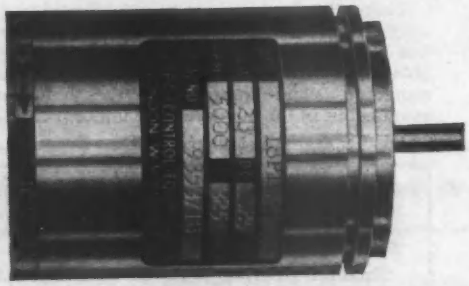

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SIZE 08.
Std. voltages 6, 12, 28. No load speed 8,500 r.p.m.
Torque 50 gm. cm. Min. stall torque 100 gm. cm.
Speed 5,000 r.p.m. Weight 60 gm.

SIZE 11.
Std. voltages 6, 12, 28. No load speed 8,500 r.p.m.
Torque 120 gm. cm. Min. stall torque 270 gm. cm.
Speed 5,000 r.p.m. Weight 145 gm.

SIZE 15.
Std. voltages 6, 12, 28. No load speed 7,500 r.p.m.
Torque 220 gm. cm. Min. stall torque 650 gm. cm.
Speed 5,000 r.p.m. Weight 305 gm.

SIZE 18.
Std. voltages 6, 12, 18. No load speed 7,000 r.p.m.
Torque 325 gm. cm. Min. stall torque 1,200 gm. cm.
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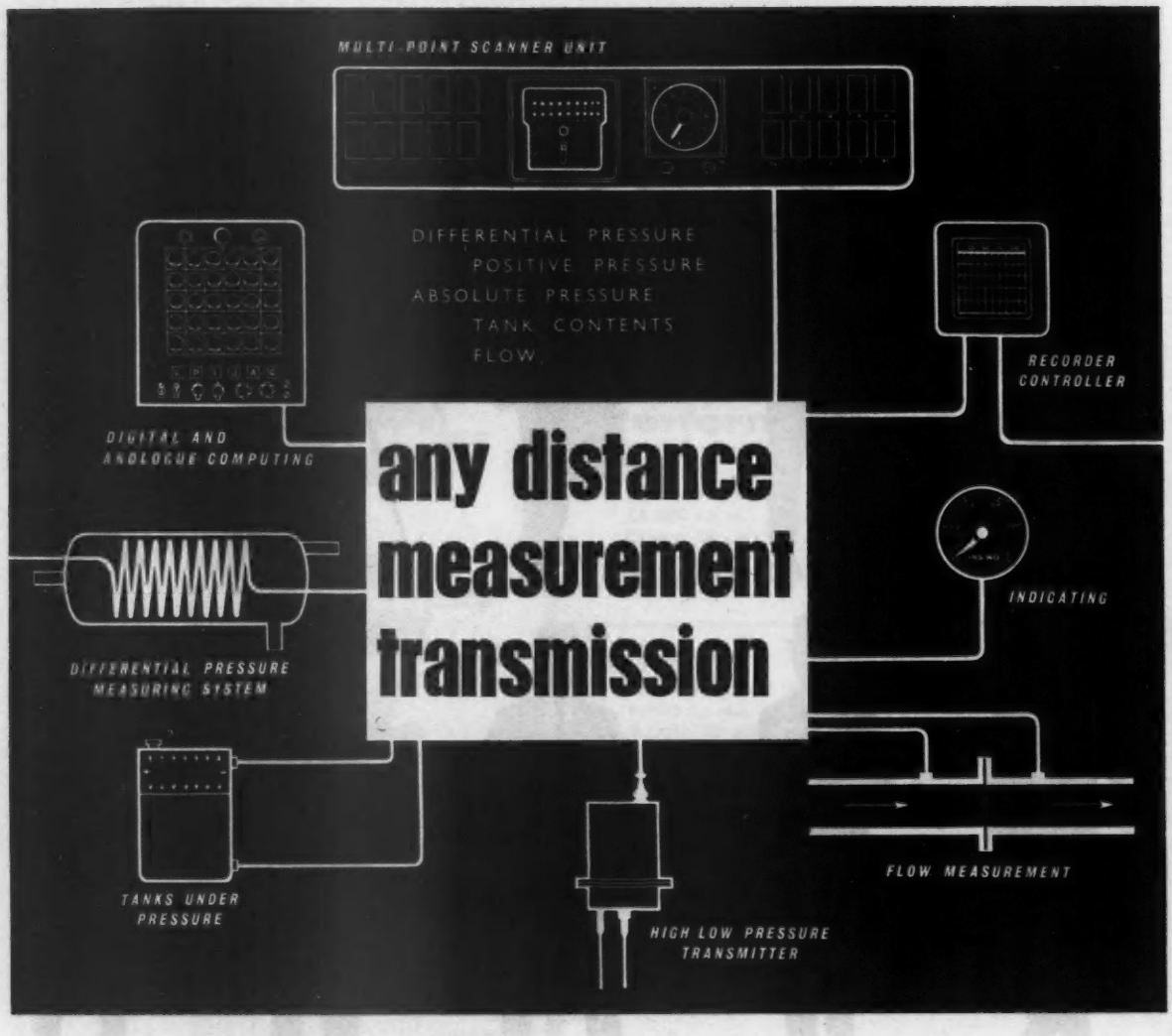

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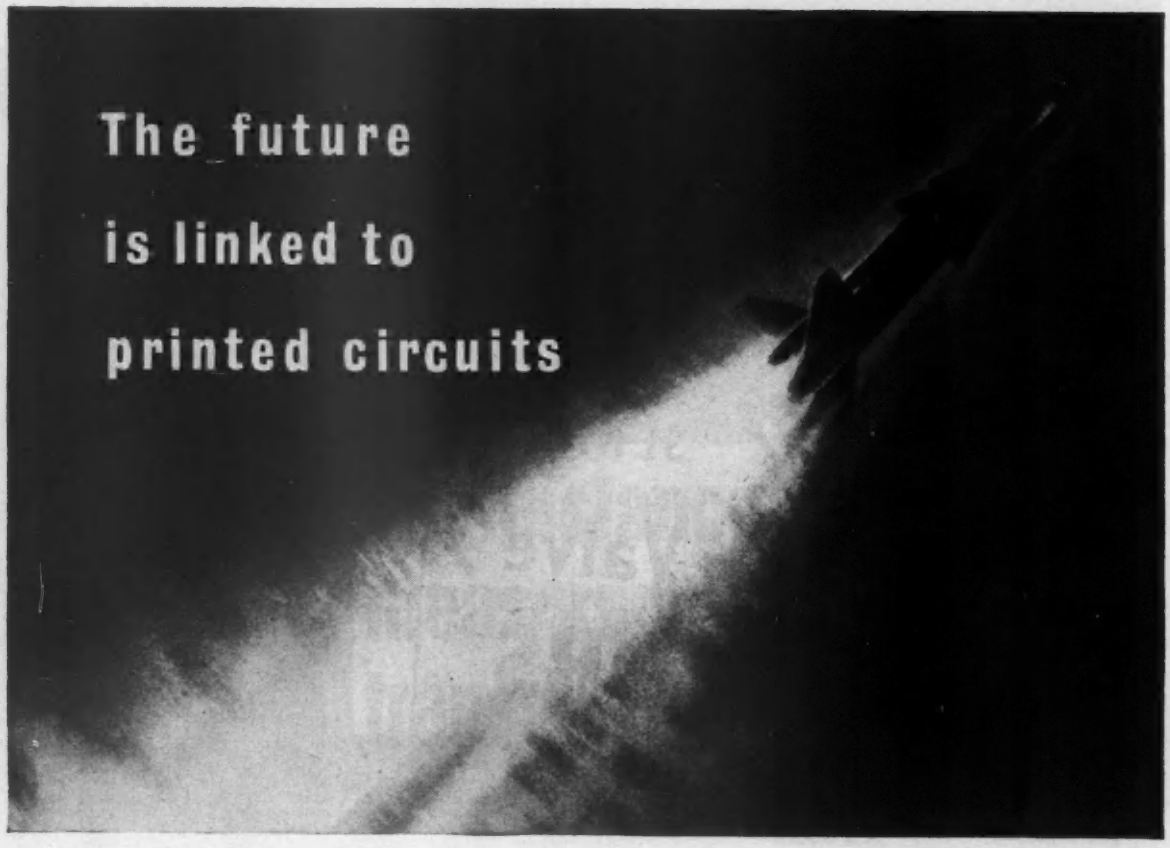

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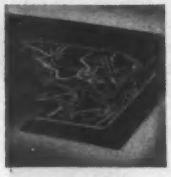

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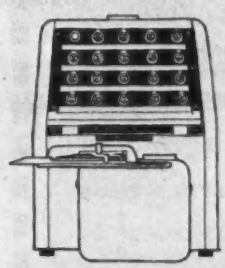
the day they threw the pencils away at Northrop



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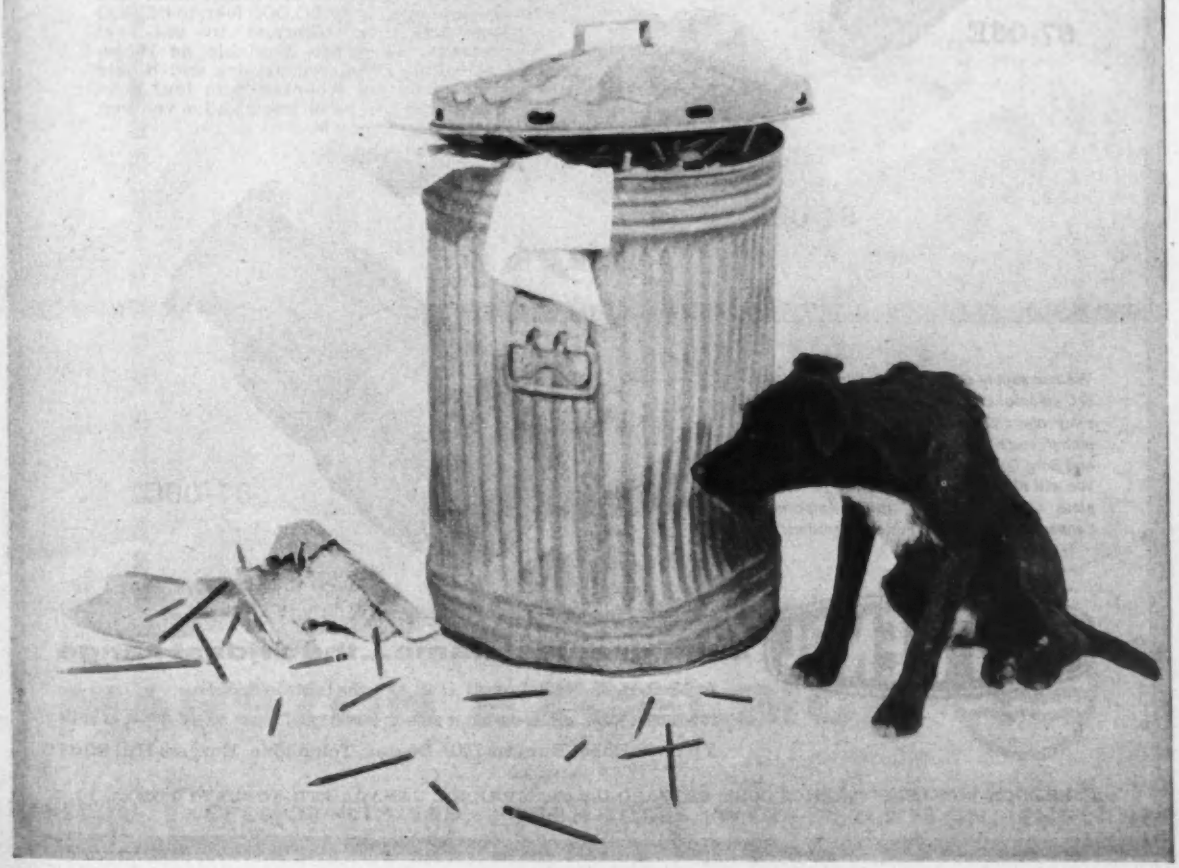
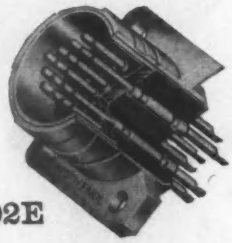


In step with the future of electronics

Amphenol Research and Development Programmes, here and in the U.S.A. ensure that the growing complexity of electronic equipment, accompanied by environmental stresses to a degree undreamed of not so many years ago, are matched by advances in connector design and reliability. The experience of more than 25 years and many of the developments originating in high level research, for military requirements for example, are incorporated in the Amphenol Connectors now at the service of Industry.

MINNIE miniature connectors

67-06E



67-02E

Rigid test schedules far beyond likely operating conditions help to ensure the complete reliability of Amphenol Connectors. MinniE multi-contact, quick disconnect bayonet lock connectors are, for example, tested for altitude-moisture resistance by submersion in salt water, and altitude cycling to 80,000 feet, to 65,000 feet and then returned to sea-level pressure. They are available as Plugs, Cable and Panel receptacles and Single Hole mounting receptacles in four constructions, five shell sizes and seventeen insert arrangements.

We can supply miniature co-axial connectors, co-axial changeover switches (hand or relay operated) and micro-potentiometers manufactured by our R. F. Connector and Borg Divisions.
We will also be pleased to quote for complete cable assemblies, using Amphenol Connectors, including "Potted" versions.

67-06C

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AMPHENOL—BORG LIMITED
AMPHENOL ELECTRONICS DIVISION
Victoria Road, Burgess Hill, Sussex. Telephone: Burgess Hill 85616

AMPHENOL-BORG ELECTRONICS CORP. CHIGAGO U.S.A. AMPHENOL CANADA LTD. TORONTO 9 ONTARIO.

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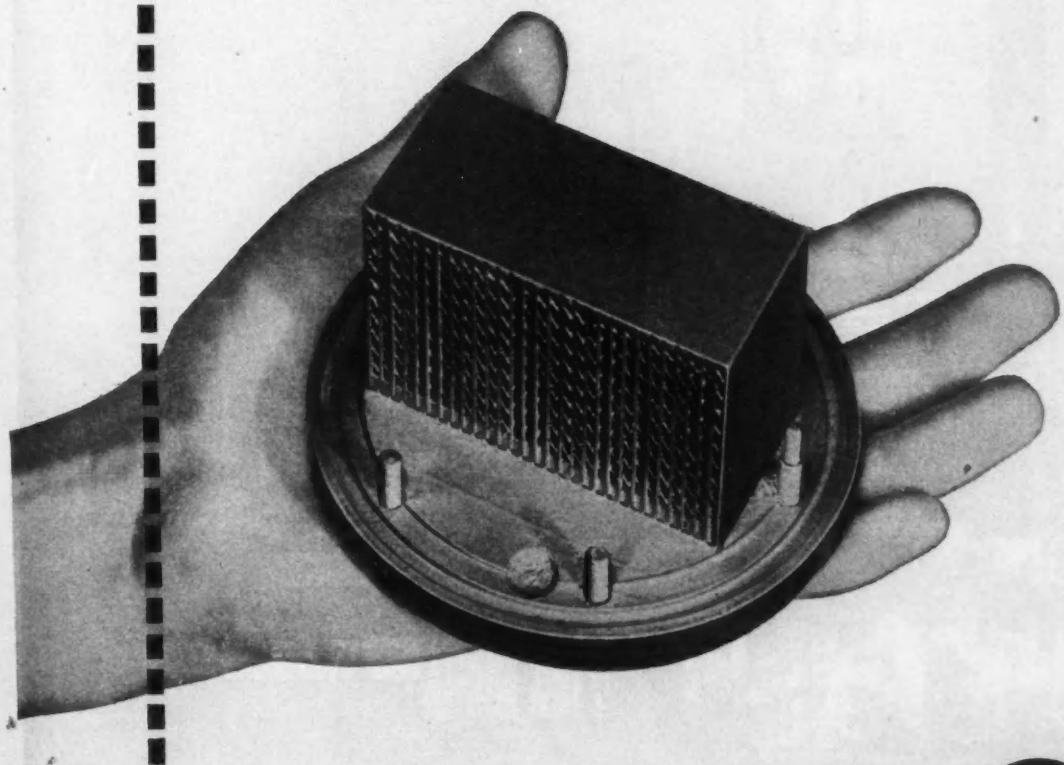
In a sense it's an optical illusion. A magnetron valve cooler made by Marston sits snug in the palm of the hand—but, thanks to the ingenious corrugations of the secondary surface heat-exchanger, it presents two-and-a-half square feet of surface area. This is just one instance of the compact coolness Marston offers the electronics industry. Marston heat-exchangers, whether air- or liquid-cooled, are designed specifically for preserving component life and efficiency and reducing the drift of transistor characteristics. Don't design round these problems: Marston can help you overcome them.



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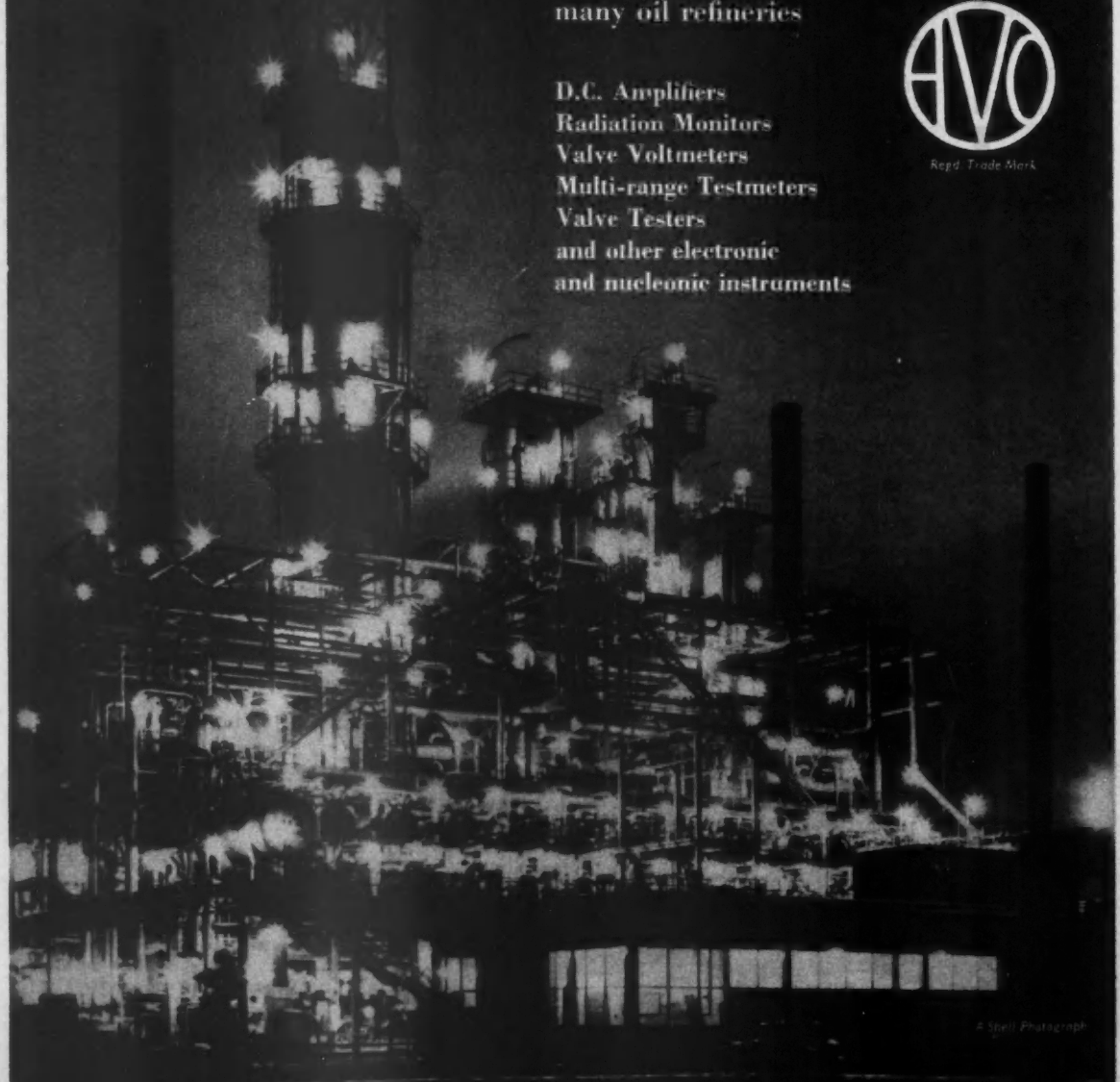
MAR 265

AVO INSTRUMENTATION

AVO instruments are in permanent use at many oil refineries



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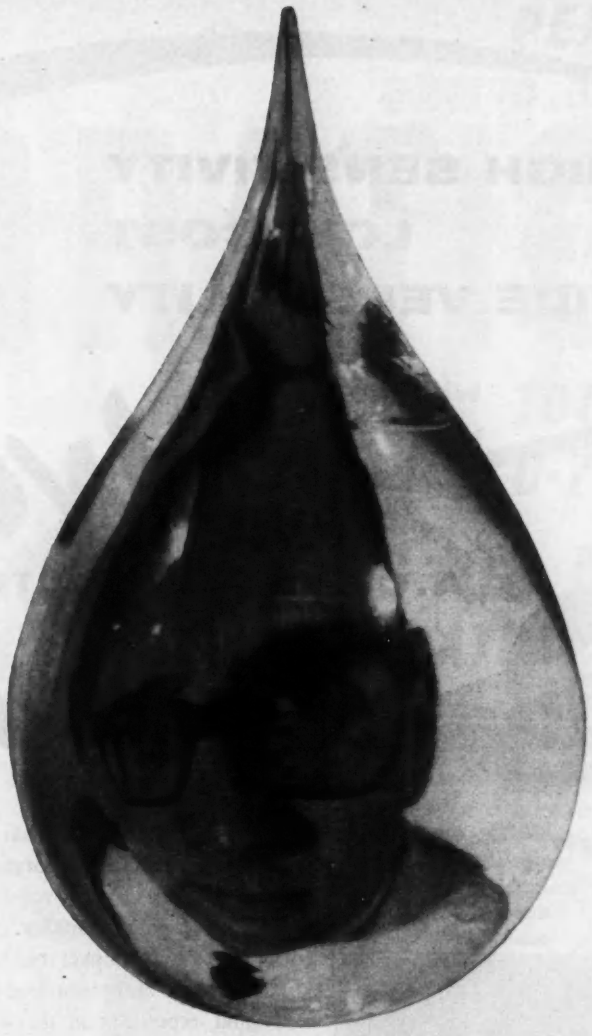

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The VG. 108 MK II, available as a trunnion mounted Vibrator, presents a good compromise in a very broad field of Test requirements. Although this machine takes up a relatively small floor area, it retains sufficient weight to enable a high foundation mass to thrust ratio to be maintained. In performance the first structural resonance (unloaded condition) appears at approximately 2kc/s but under 'load' conditions subsequent damping enables the vibrator to be used to beyond 7kc/s. The full detailed specification is available on request.

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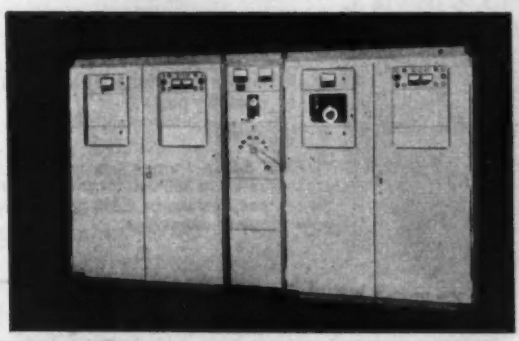

Illustrated left, is a PA 20KVA Power Amplifier; and above, the E501 'g' Control Amplifier.

*

Whatever the problem .. whether fatigue, torsional or structural investigation .. consult

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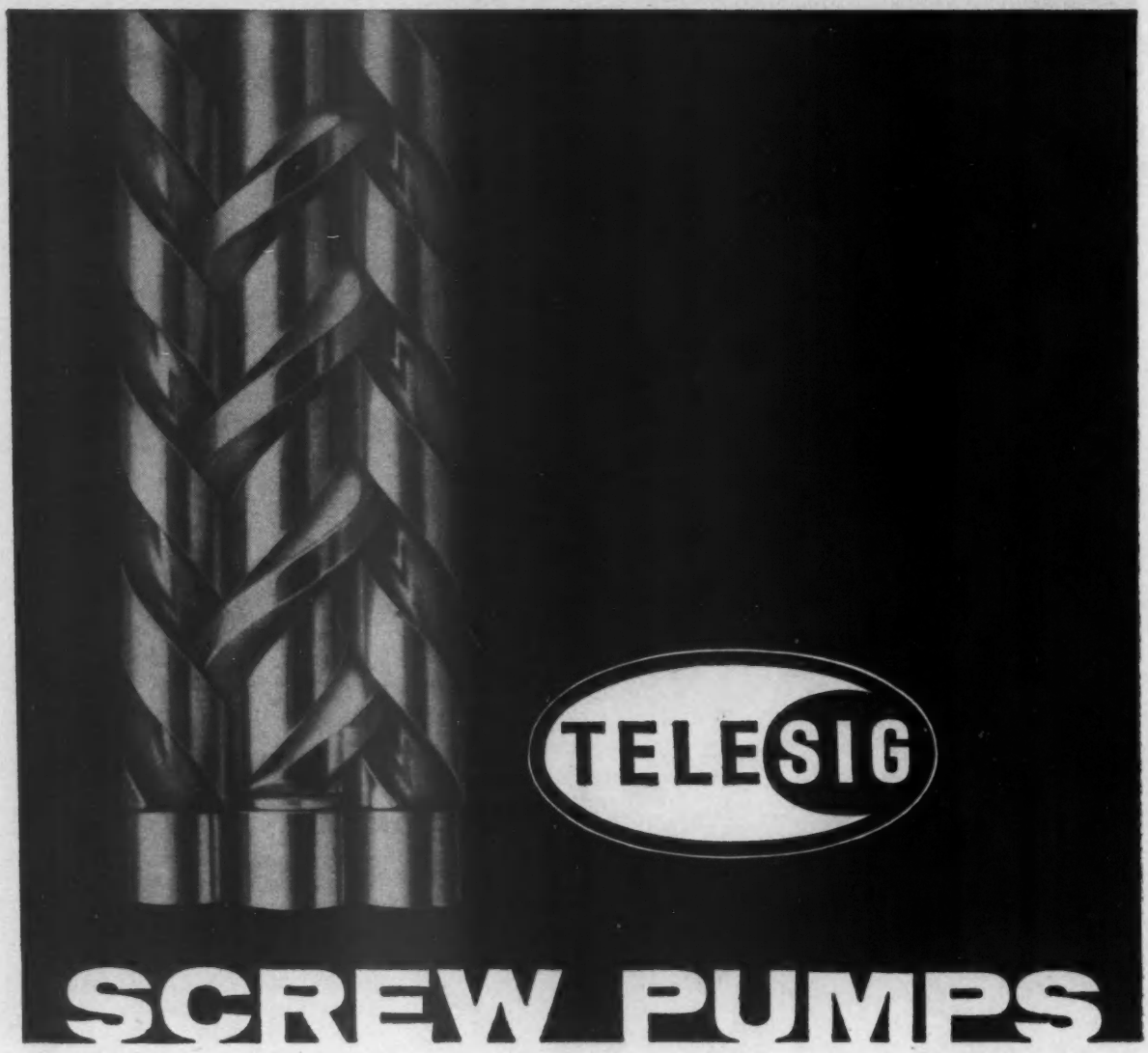

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- Near-silent operation.
- Simple construction.
- Minimum maintenance and easy replacement of working parts.
- Long life.

TELESIG Screw Pumps are made in three basic ranges: for low pressures up to 300 psi, for medium pressure up to 1000 psi and for high pressures up to 2,500 psi. 42 sizes are available covering a wide range of capacities.

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Screw Pumps by Telehoist

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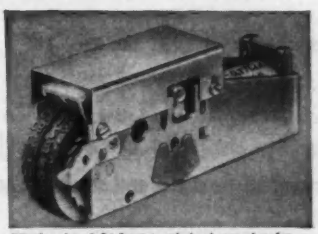
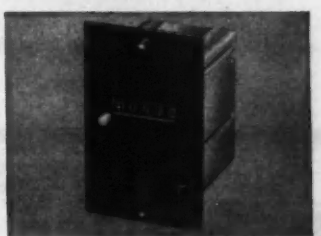
- **Versatile range with extensive applications**
- **Offering utmost reliability**
- **In some cases extremely compact**

TMC Elmeg Counters are as near perfect as they can be made by the human skills of technical experts with years of experience and the most advanced equipment at their disposal. As a range, they are exceptionally versatile—offering a choice which should match up to even the most remote requirements. Available in "Print-Out" and "Read-Out" form, they have fast operating speeds of up to 40 per second. They operate on up to 240 Volts, with uni-directional or bi-directional motions. Re-setting to zero by electrical, mechanical or electro-mechanical methods. There are auxiliary contacts operating on each revolution of a numbered wheel. The range includes counters for flush panel mounting and surface mounting. No special servicing is required.



ZDmh—An 0-24 hours printout counter for vertical mounting.



PZSe1R—5-digit counter with electrical and mechanical reset.

The number of applications for which TMC Elmeg Counters can be used to advantage are far too many to list in detail. The following will act as a general guide:

- ✳ In conjunction with proximity switches or photocell equipment on production flow lines.
- ✳ In factory statistical equipment.
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You can register up to 9,999,999 on TMC Elmeg Counters

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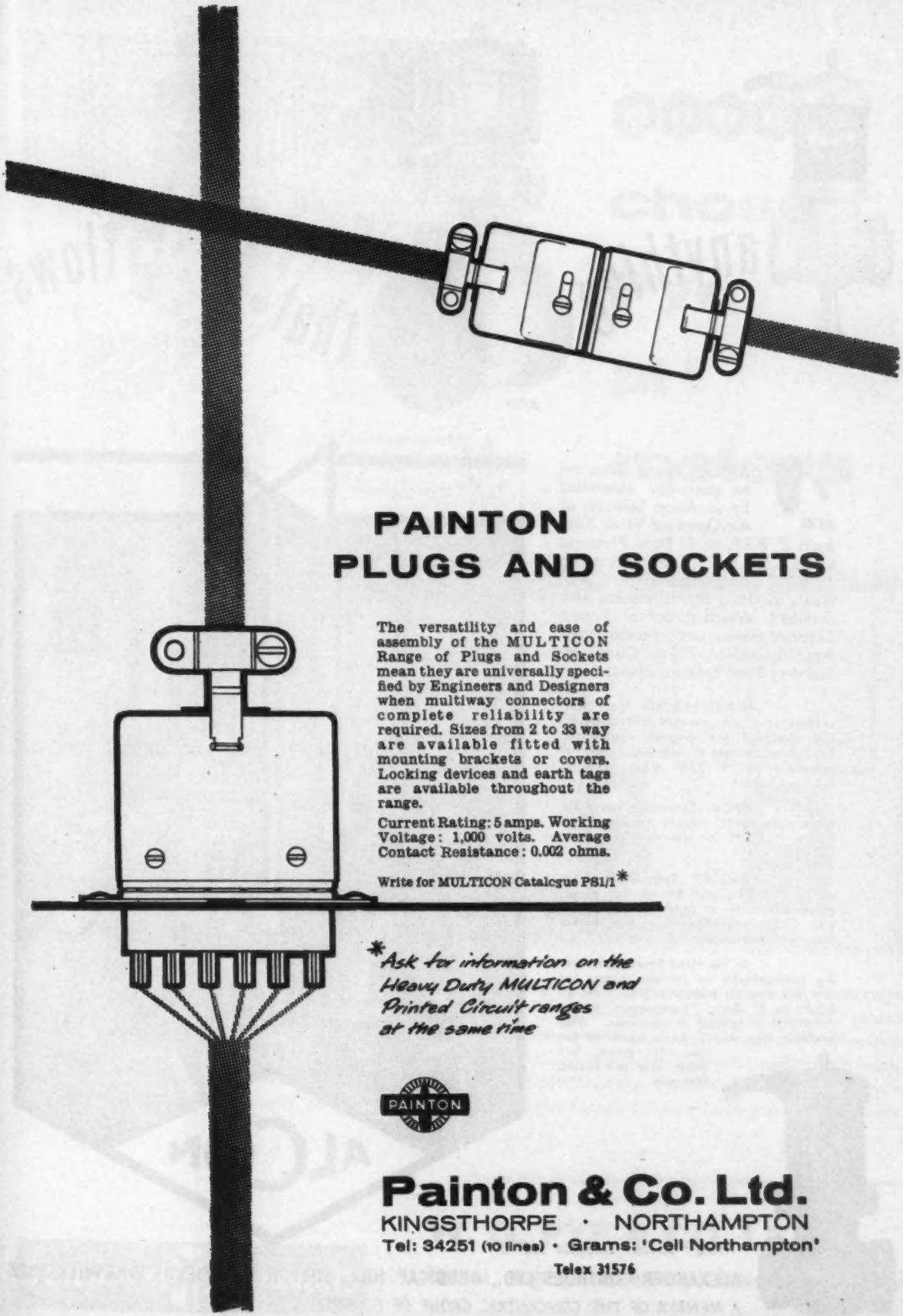

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The versatility and ease of assembly of the MULTICON Range of Plugs and Sockets mean they are universally specified by Engineers and Designers when multiway connectors of complete reliability are required. Sizes from 2 to 33 way are available fitted with mounting brackets or covers. Locking devices and earth tags are available throughout the range.

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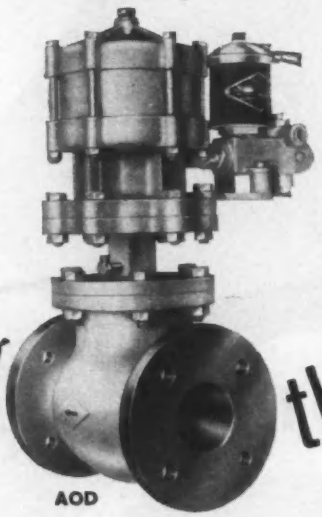
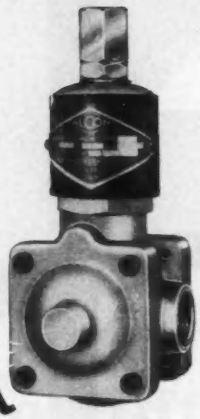


AOD



SPC 3

ACO

All Liquids and Gases can be positively controlled by an Alcon Solenoid or Air-Operated Valve. Sizes from $\frac{1}{8}$" B.S.P. to 8" Bore. Pressures up to 1,500 p.s.i. Temperatures up to 300°C. Body materials to suit all media including corrosive acids, with Standard, Weatherproof or Buxton Certified Flameproof Solenoid Housings. Glandless, Fluon Glands or Stainless Steel Bellows Glands.

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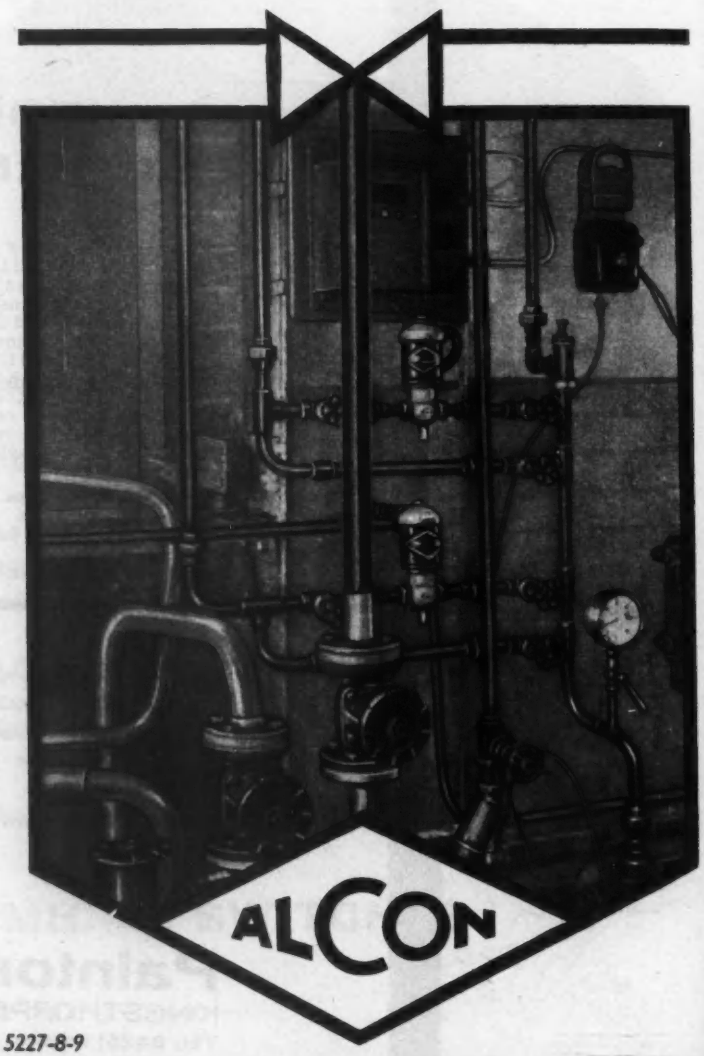
ACH—Hand Reset type, closing automatically on current failure, for low and medium pressures. Sizes from $\frac{1}{4}$" B.S.P. to 6" Bore. Inexpensive, simple construction, reliable in operation. Also available type ACHL. Lever operated for use with steam, hot water and pre-heated fuel oils.



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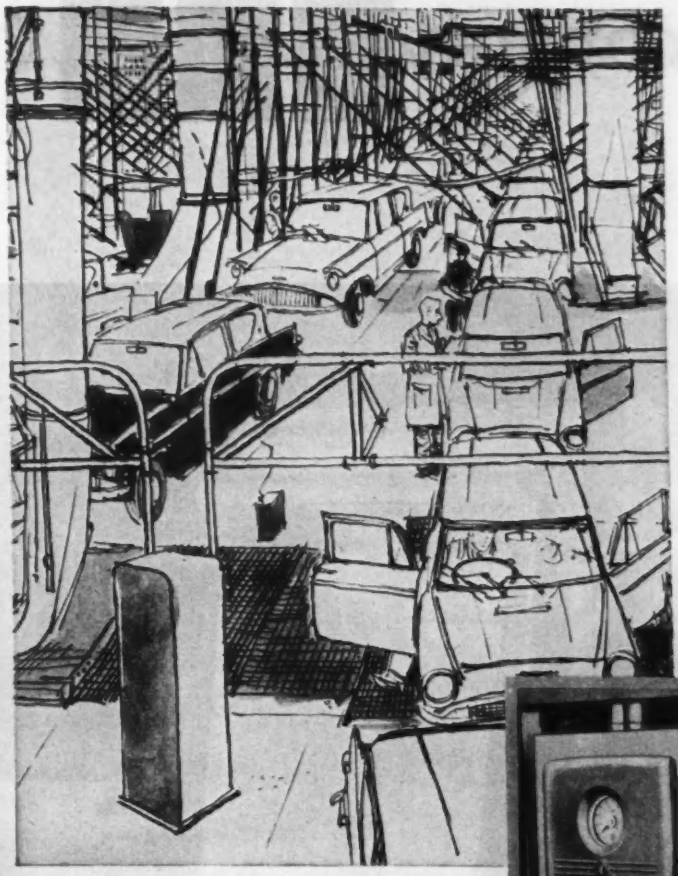
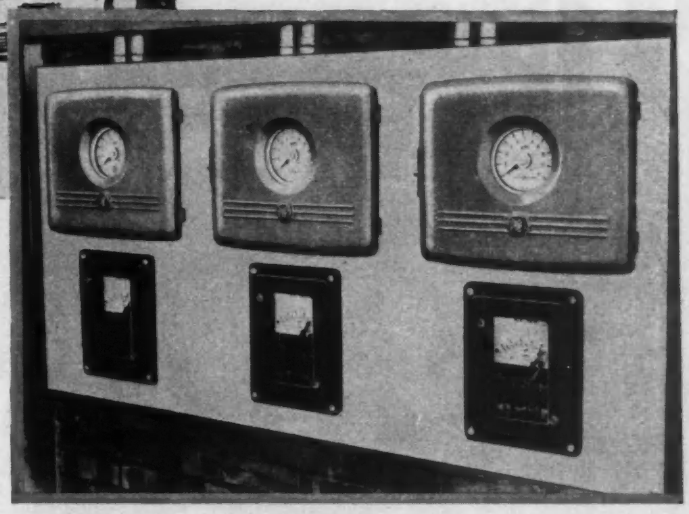


FORD chose Pye pH meters



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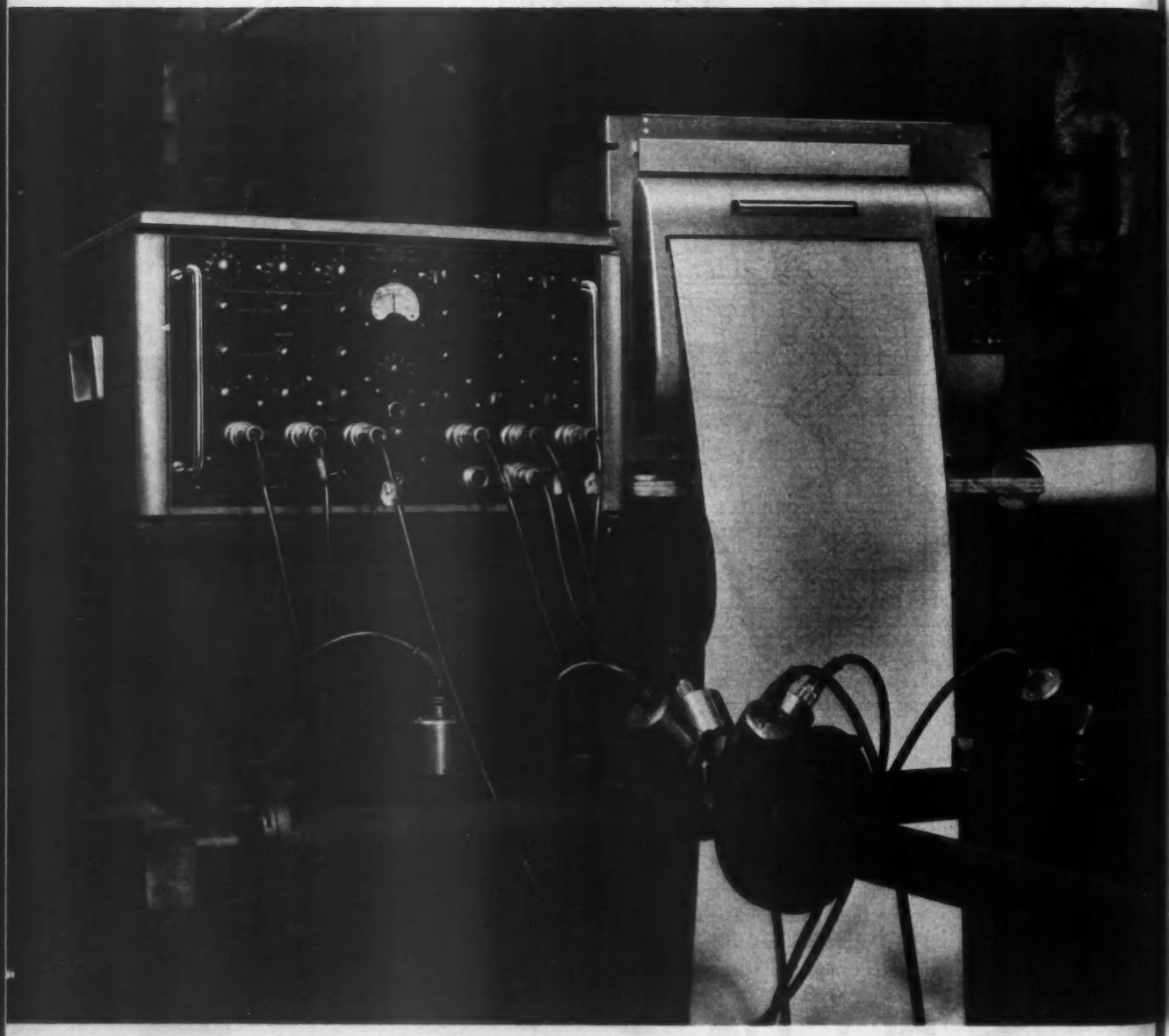

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PNEUMATIC

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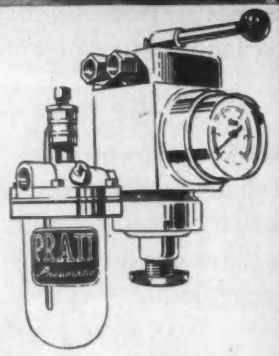
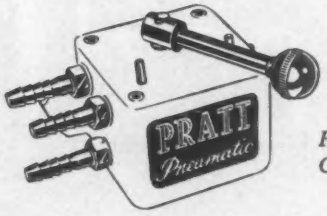
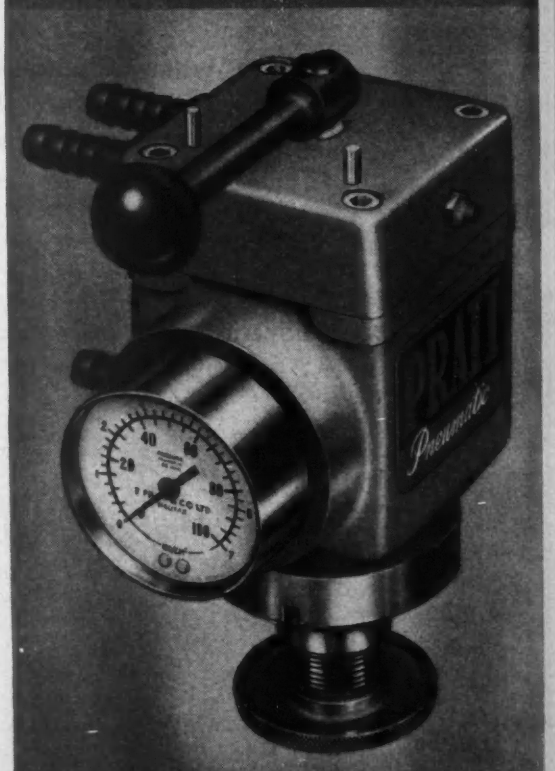
Pratt Hand Operated Air Control Units Type V.6 Fitted with Oil Mist Lubricator





Pratt Hand Operated Control Valve Type V.2



This unit combines a hand operated control valve, dial pressure gauge and pressure reducing valve in one neat, compact and efficient assembly. The design of the valving mechanism is such that extremely long life and finger light operation is guaranteed. The valve disc is fully-floating and consequently any tilt of the operating shaft due to wear over a long period of time does not affect the efficient working of the valve. Essential working parts are non-ferrous to ensure freedom from corrosion due to moisture in the air line. Tapped holes are provided in the rear of the body for fixing. Removal of the pressure gauge will expose bolt holes for front fixing if required. Standard port size ¼" B.S.P.

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Pratt Control Units cover a wide range of applications in the Pneumatic field. We shall be pleased to send you full details on request.

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HALIFAX ENGLAND

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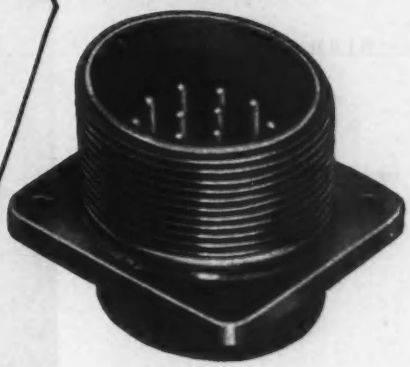

THORN AN SERIES

The Thorn AN series of electrical connectors includes solid shell/ general purpose, pressurised and environmental resisting ranges. By specifying Thorn, designers are assured of a *genuine* AN connector for their installations . . . a connector designed strictly to the current MIL specifications.

Note these outstanding design and operating features.

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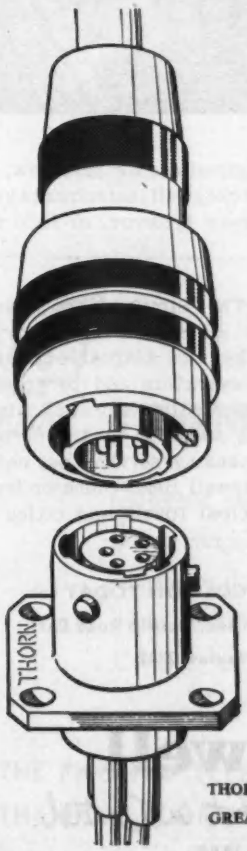
- *Resilient insert eliminates shrinkage problems and ensures superior electrical performance through high arc resistance, high dielectric strength and low moisture absorption.*
- *Thorn grommet increases flash-over and creepage distances, excludes dirt and moisture.*
- *Pressurised, water-tight, radio-quiet assembly.*
- *Maximum performance, minimum weight.*



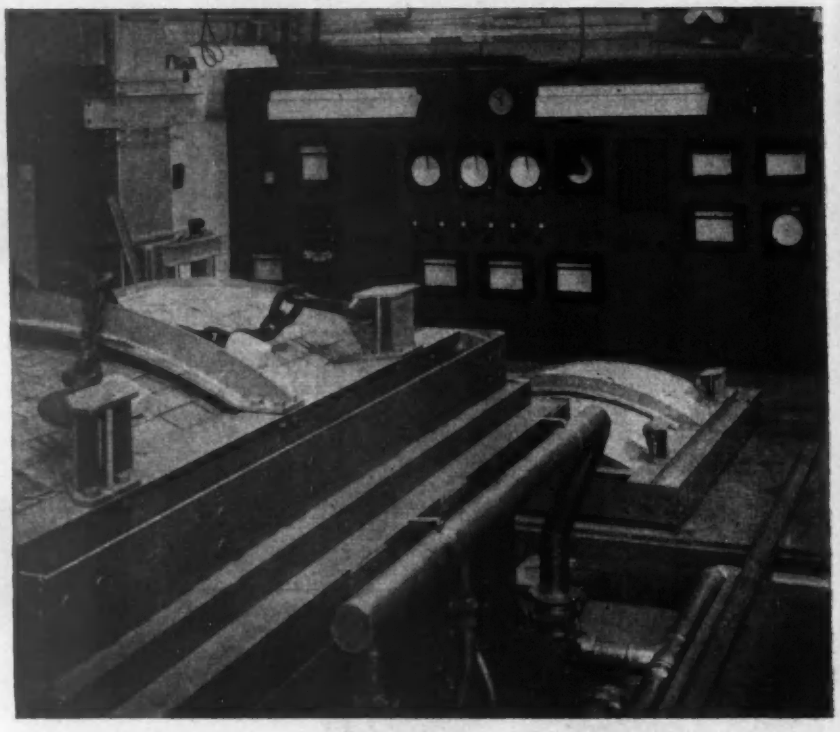
THORN PYGMY PT SERIES

A new range of miniature connectors that satisfy the requirements of R.C.S. 321 (Category 40/100, class H.2 sealed items). Thorn Pygmy connectors are ideal for applications where space is limited and weight represents a critical factor of the installation.

- *Heavy gold plating over silver on all contacts.*
- *Performance unimpaired over a continuous temperature range from —40° to +100°C.*
- *Visual and audible inspection of coupling—perfect for "blind" locations.*
- *Three-point bayonet lock; perfect axial alignment of mating parts at all times.*
- *Five-key polarisation—positive protection against mis-mating or cross plugging.*
- *Miniaturised—light weight—compact.*

THORN ELECTRICAL INDUSTRIES LTD SPECIAL PRODUCTS DIVISION (incorporating Components and Connectors)
GREAT CAMBRIDGE ROAD ENFIELD MIDDLESEX TEL: ENFIELD 5353

Experimental Batch Furnace
fully instrumented



B.I.S.R.A. begin a new chapter in research with their new experimental forge furnace. It will give the steel industry the answers to many long-standing questions on furnace design, operation and control

The Energy Section of B.I.S.R.A. is now studying how to improve efficiency in batch type heating processes. And Honeywell Instrumentation is helping to write up the essential facts and figures —programming the heating cycles, too.

MULTI-RECORDING. Four ElectroniK 12-point Recorder/Controllers continuously record the data from more than 100 thermocouples dispersed in the walls, chamber, flues, air ducts, recuperator, stack of the new experimental forge furnace, and in the 3-ton ingot.

PROGRAMME CONTROLLING. A master temperature Controller sets the heating cycle and governs secondary controllers for fuel flow. At the same time, other Honeywell instruments keep a critical eye on furnace pressure, or help the analysis of flue gases.

BIOGRAPHICAL NOTE. Similar instruments are used throughout B.I.S.R.A's laboratories. Versatile, accurate, they are adaptable to pure research, pilot plant operation and to process control on the largest scale. In every application they are made doubly valuable by the design, engineering and maintenance service they carry with them from Honeywell Head Office or from branches in the principal towns and cities in the United Kingdom.

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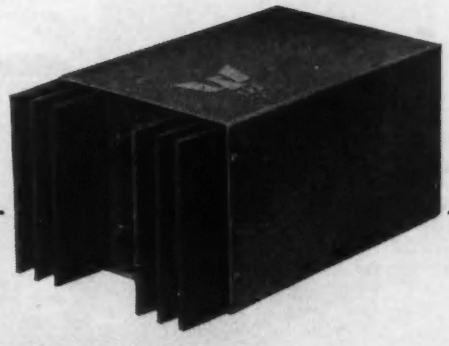

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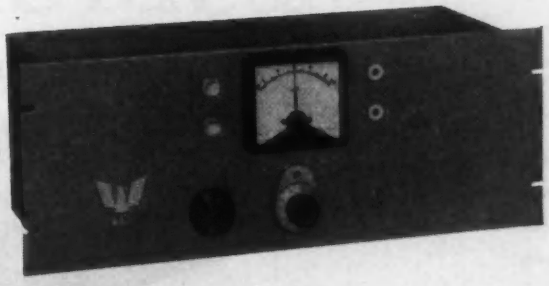
Inverters for fluorescent lighting from 12 volt d.c. supplies cover the range from a single 6" tube to six 24" tubes or equivalent.
Inverters for 12v. d.c. to 50 c/s or 400 c/s a.c. up to 100 W.
Constant frequency and locked frequency inverters for camera and tape recorder operation.
Inverter-rectifier systems for d.c. to a.c. conversion.



TRANSISTOR *Controller*

Magnetic amplifier intermediate stage, saturable reactor power stage. A temperature controller for use with a platinum resistance thermometer to provide power control up to 60 KW 3-phase. No mechanical switches. Constant current characteristic for platinum furnaces.

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British Railways select

* PELAPONE CONTROL and rotating plant

for new signal power supplies

Determined to enhance their proud tradition of safety, reliability and continuous service, British Railways are pressing ahead with their intensive modernisation programme.

This includes the installation of completely new signal power supply systems at Manchester and Crewe.

The choice of control equipment and rotating plant for these vital main line centres was PELAPONE— the equipment with the dependable high performance British Railways—and British Industry—demands.

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Controlled Power–Continuous Power

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Knowing how important speed is to the designer this Company provides a special service in which speed is the keynote. There is a B. & R. department equipped to produce one off or small quantities for customers' prototype equipment. Please let us have details of your requirement.

Why not write and ask about it: or telephone Harlow 25231.

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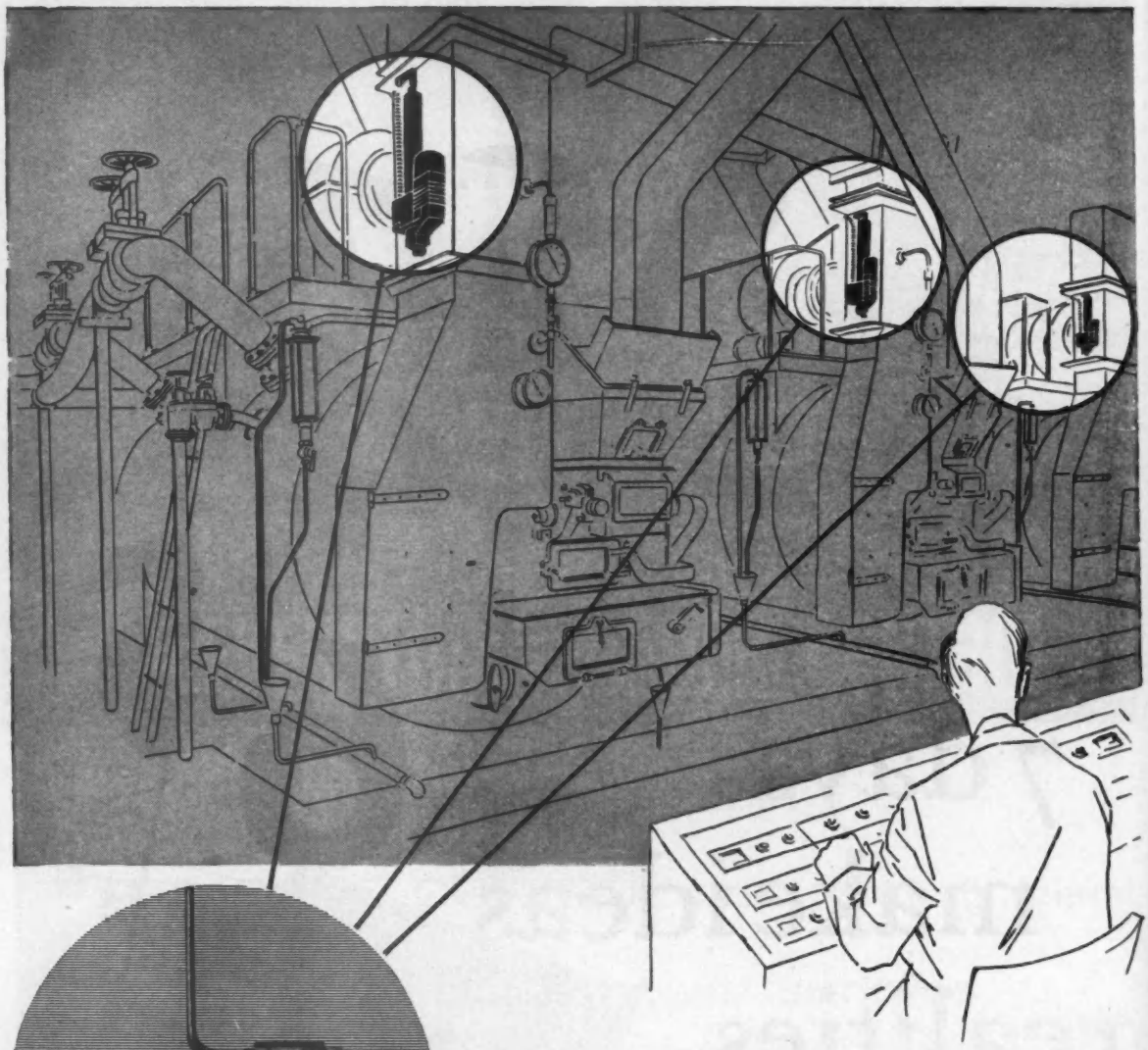
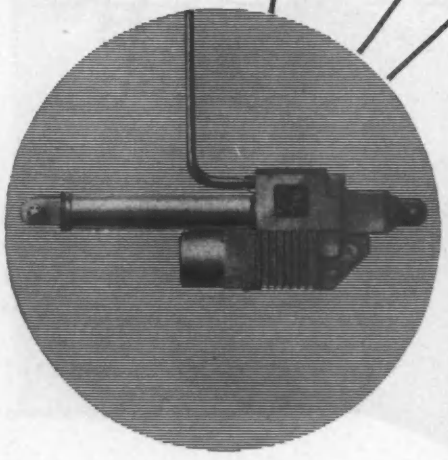
Telephone: Harlow 25231/4 *Member of the Gas Purification Group.*





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Teleflex Industrial Actuators solve many problems in the control of heavy loads.
Remotely — electro-mechanically — simply — economically — accurately.

Teleflex actuators for industrial remote control

Suitable for operating equipment which is normally inaccessible (valves, dampers etc).

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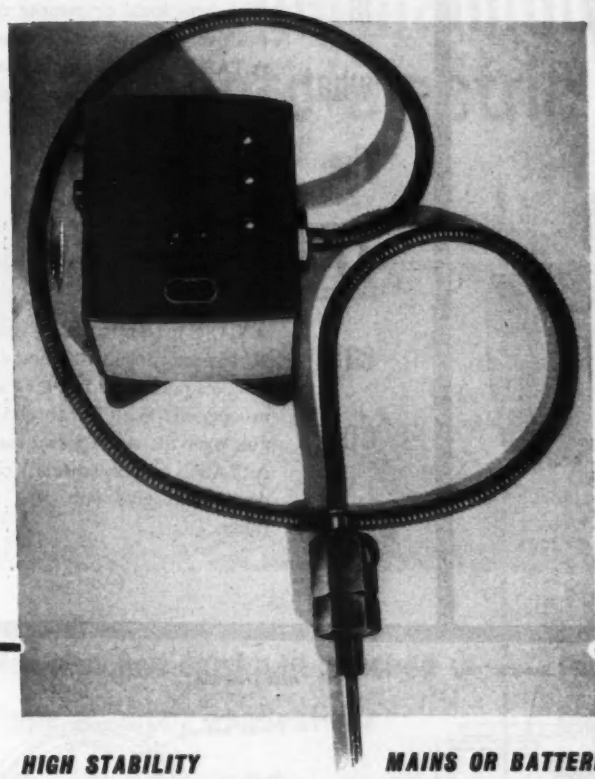
Nothing touches

THE AIRMEC PROXIMITY DETECTOR

TYPE N266



The Proximity Detector Type N266 is a capacity-operated switch with a wide range of application in the fields of measurement and control. It is operated by any physical variable appearing as a small movement. The equipment consists of a control unit housed in a robust cast light-alloy industrial case, sealed against the ingress of dust and moisture, together with a sensing probe. The probe, which contains no electronic components and is therefore unaffected by heat or rough treatment, may be fitted with a cover for use in liquids or corrosive atmospheres.

ASK FOR LEAFLET 199A

HIGH STABILITY

Even when the highest sensitivity is in use, mains voltage variations over the range 180–260 volts and temperature changes of 20° can be tolerated without significant change of operating point. This means that once the equipment has been initially set up it will need no further attention.

RELIABILITY

A transistorised printed circuit is employed for its high reliability.

MAINS OR BATTERIES

Either a mains power unit or a battery unit is fitted to order. Under maximum current conditions the battery life is in excess of 200 hours, at 4 hours per day, but in many applications the battery life may well be extended to the shelf life.

EXCEPTIONAL SENSITIVITY

Its sensitivity is such that it will detect a capacity change of 0.05 micro-microfarad, representing a movement of the order of tenths of thousands of an inch under suitable conditions.

PROBES

A variety of probes (fixed or remote) are available for a wide range of applications.

WIDE APPLICATIONS

Level control and counting, sorting, grading, gauging, limit switching and any application involving the detection of small variations in the position or nature of both conductors and insulators.

In Instrumentation Airmec

makes most things . . . better

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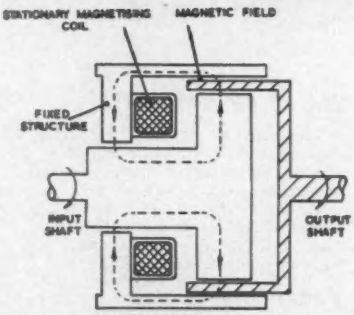
TASC unit
TORQUE AND SPEED CONTROL

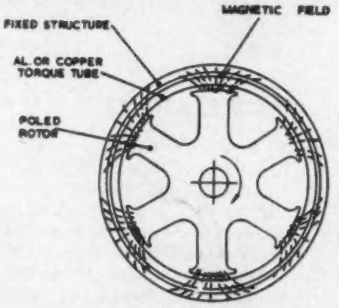
This is what the TASC unit can do

Slash maintenance costs.
Eliminate special precautions against overloads.
Give you local or remote control positively, simply and precisely.
A TASC master (Torque) gives you full control between zero and rated torque.

A TASC master (speed) gives you a 20:1 speed range with good regulation, a smooth and fast take up and no cogging. With full torque available over the entire speed range.
A TASC master (special) can be devised to give you 50:1 speed range.

this is what the TASC unit is





The TASC unit is a new application of the Faraday disc principle.
It consists of two independently rotating members magnetically linked by the field from a fixed coil. The transmitted torque is proportional to the coil current. It is thus an inherently controlled torque device.

The TASC Unit is unaffected by stall-down on output no sliprings or brushes—low output inertia—no out-of-balance forces—sealed bearings—sizes from 1/4 to 10 h.p.

Find out more about the TASC unit
TORQUE AND SPEED CONTROL

This coupon with your company letterhead will bring you full technical details and a demonstration at your works if you require it.

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COMPANY .....
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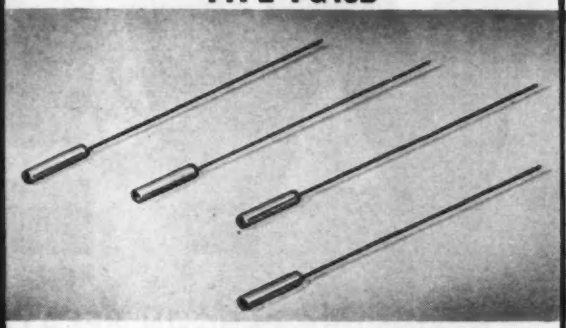
PYE ELECTRIC LTD. (LOWESTOFT DIVISION)
OULTON WORKS, LOWESTOFT, ENGLAND
Telephone: Lowestoft 1900 Telegrams: Pylec Lowestoft

SenTerCel

germanium junction photo-electric cells

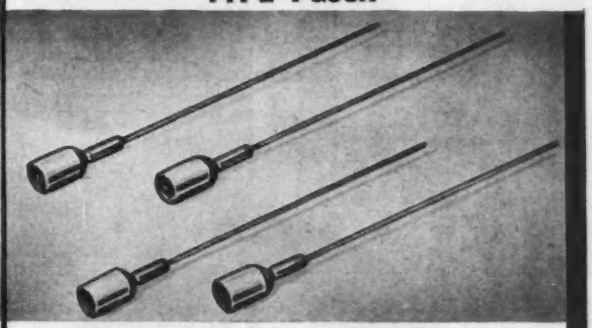
TYPE PG40B



for punched card and punched tape scanning applications

The result of manufacturing development work on the type PG40A, this cell consists of a germanium element with p-n junction parallel to the largest face. The overall diameter is only 0.080" and this reduction in size offers greater facility for mass grouping where the devices are used for scanning punched card and perforated tape.

TYPE PG50A



for machine tool control and industrial counting applications

Characterized by small size and large output. This type has an impedance and output characteristic which enables it to be used with both relays and valve circuits. The cell consists of a germanium element with a p-n junction parallel to the largest face.

Full electrical and spectral characteristics are given in Technical Data Sheets obtainable from:—

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60/5MF

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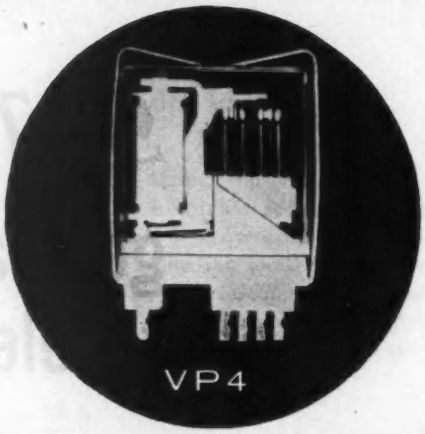

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MINIATURE PLUG-IN RELAYS

British made . . .
for long life
and perfect contact.

Features:

* Size:
  Type V.P.2. 0·75″x0·96″ Panel height 1·175″ (with socket 1·35″)
  Type V.P.4. 0·75″x1·18″ Panel height 1·175″ (with socket 1·35″)
* 2 or 4 pole changeover
* Operating voltages: 6–138v D.C.
* Operating times: 3½ to 7½ milleseconds
* Operating life: in excess of 10^7 operations
* Contact ratings: 1 amp at 100v. Maximum watts: 30w
* Contact material: fine silver. Other contact materials will be available at a later date
* Plug-in and fitted with dust cover.

Varley
REGD. TRADE MARK

miniature plug-in relays

British made

GUARANTEED EX-STOCK DELIVERY

For further information write:—

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A high-grade range for small-bore services

These valves are of direct-acting spring-and-diaphragm type, suitable for small diameter lines on liquid, steam, air, or gas service. Though of simple, robust character, they are much more fully considered in design, construction, and range of application than is usual in valves of this class.

Accurately known characteristics, plus a wide choice of interchangeable control springs and trim types and sizes, ensure correct matching to conditions and predictable quality of control. Once adjusted for service, these valves will give dependable operation over long periods without further attention.

BODY $\frac{3}{8}$", $\frac{1}{2}$", $\frac{3}{4}$" and 1". Cast iron, bronze or steel.

TRIM Metal-to-metal (flat or needle stopper), or fluon soft-faced (renewable).

DIAPHRAGM Neoprene (nylon re-inforced), or metal.

MAX. INLET PRESSURE Up to 1200 psig., according to material, service temperature, and trim size.

MAX. REDUCTION RATIO Up to 500 to 1, according to flow capacity required.

MIN. REDUCTION RATIO 1·2 to 1.

MAX. TEMPERATURE Up to 600°F., according to materials.

For full specification and performance data, see Publication No. 228B, free on request.

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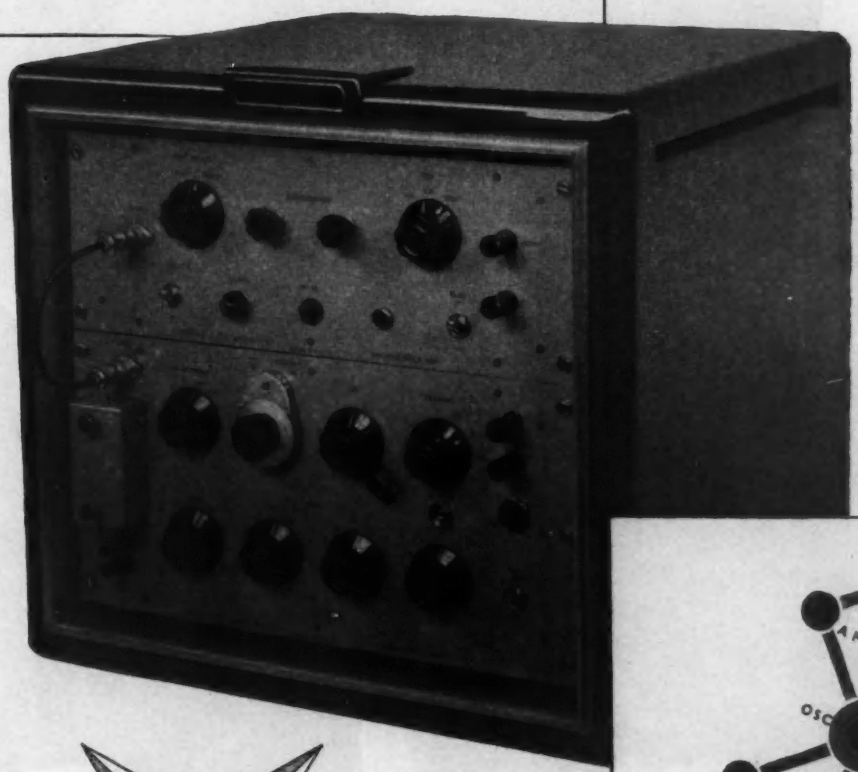
J. BLAKEBOROUGH & SONS LTD · BRIGHOUSE · ENGLAND

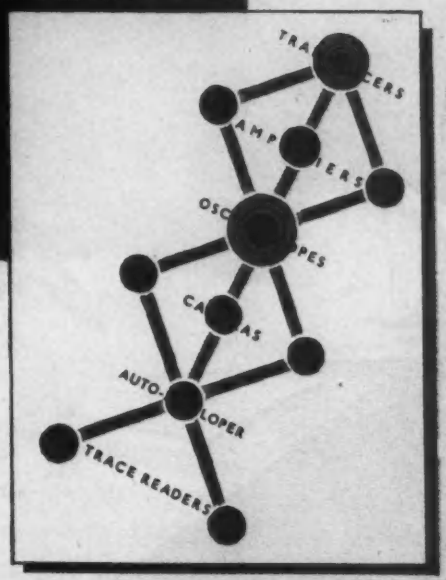
E6Q D.C. Pre-Amplifier

Are your strains determined?

Using bonded or unbonded strain gauges, this unit, part of our modular system, is offered in self contained form.

It consists of a Drift Corrected D.C. Pre-Amplifier and Bridge Panel, this unit offers Flat Frequency Responses to 20 Kcs., Amplification Factors of 250, 50 and 10, and employs gauges having a resistance upwards of 1000 ohms connected singly, paired or as four arm bridges.





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SOUTHERN INSTRUMENTS LIMITED CAMBERLEY SURREY

We are most interested in your work on Cybernetics, Dr. Philip . . .

Control has many eminent contributors whose authoritative articles are read throughout the world.

The magazine has also a staff of highly qualified engineer-journalists whose job it is to report, evaluate, and assess current work in an objective way.

The distinction between these two kinds of writing is vital rather than subtle. An engineer or scientist reporting his own work — in consultation with his colleagues — is bound to have a viewpoint different from that of a journalist reporting his assessment of the sum total of *all* their work.

That *Control* provides both types of account of a wide range of specialized activities is one of the important reasons why serious students* of contemporary work make sure they have their own personal copies for detailed study.

*' Students ' is used in a general sense here, of course. But university and other students taking courses in electronics and allied subjects are invited to apply for details of the conditions in which they can subscribe to *Control* at special rates.

RADIOVISOR
EST. 1927

* P.E control

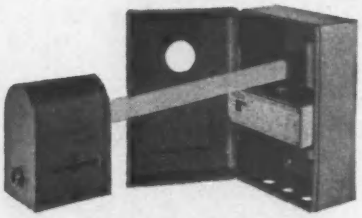

Photo-electric relay type Q.56
Uses include:—on-off switching; automatic spraying; length cutting gauge; conveyor control; process control; height gauge; limit switch; loop control; warning device; paper breakage indicators; alarms, etc. etc.

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Many factors can be measured or guarded against by keeping a check on the current of a driving motor. The Relay senses the torque of a driving motor and responding immediately to load variations, switches off the motor, indicates the variations or performs some other desired operation.

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It costs nothing to consult us—
We have over thirty years' experience

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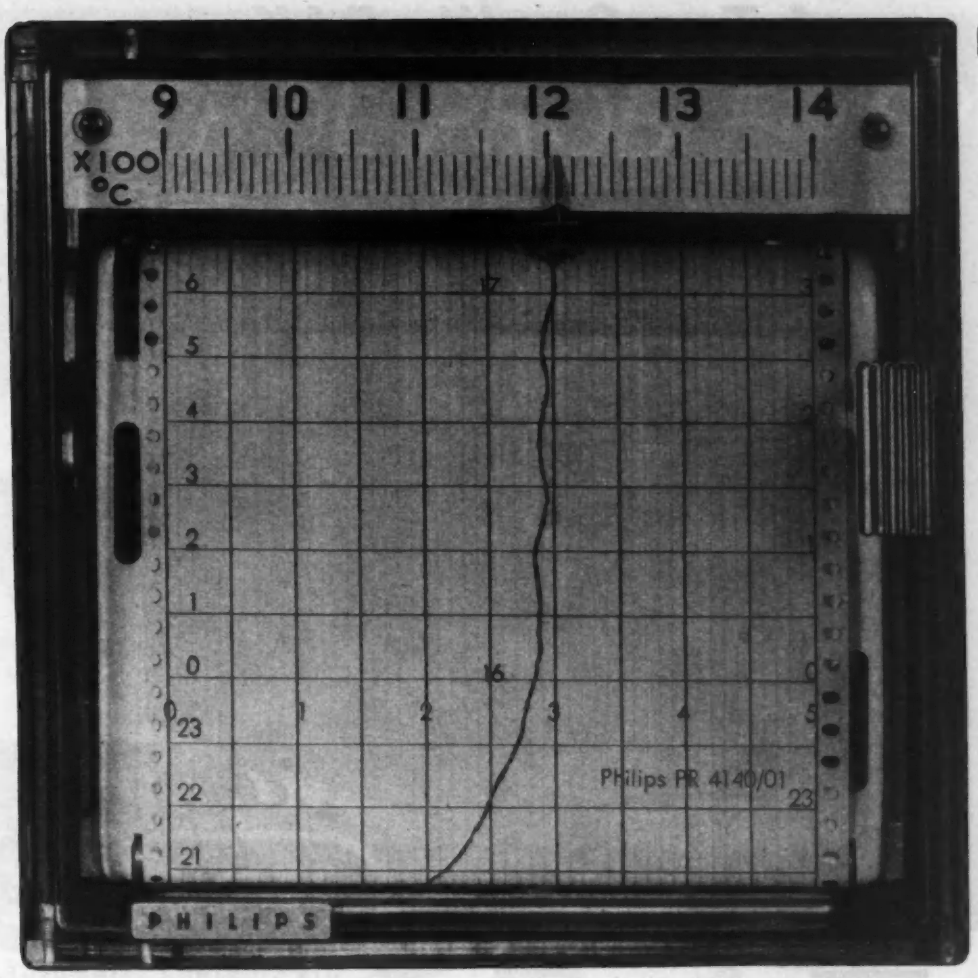

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for mV and temperature measurements
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- Reliable null-balancing potentiometer system.
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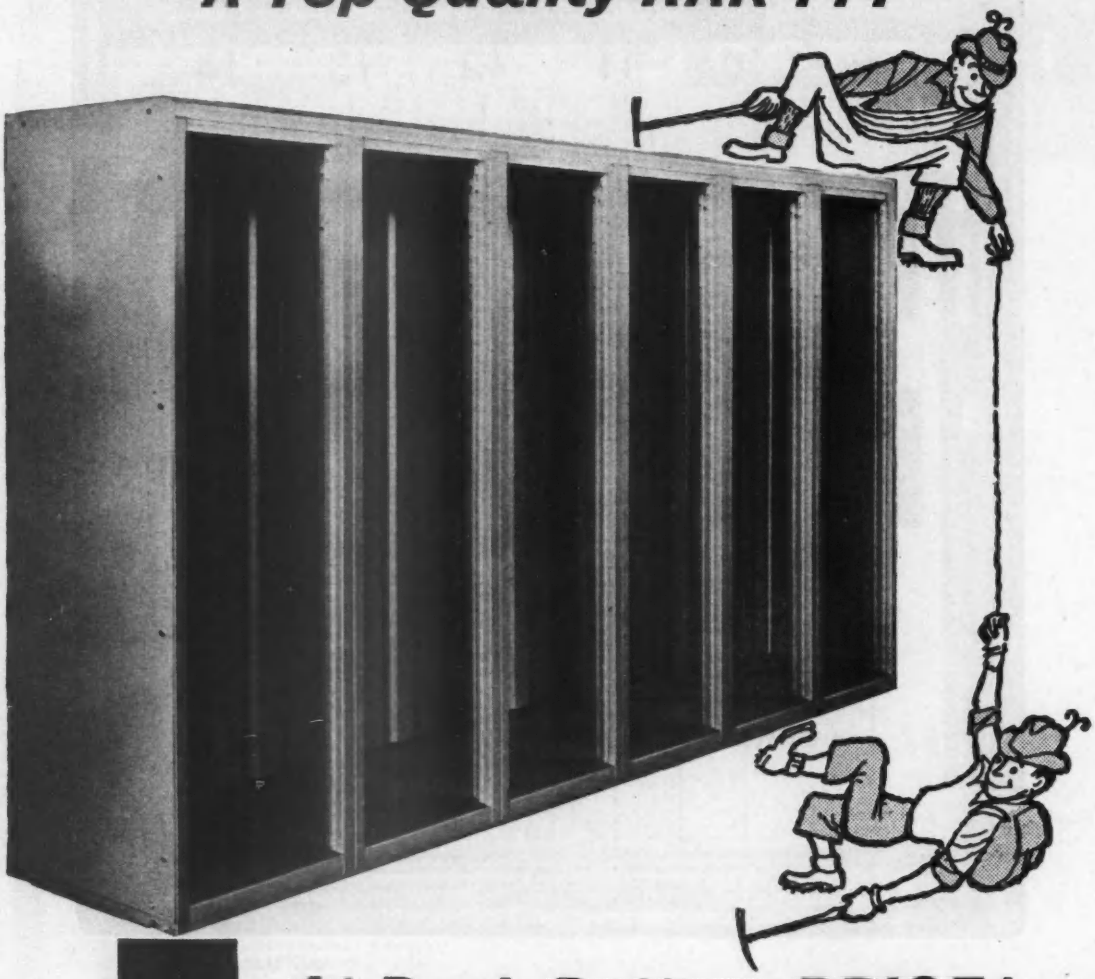
A Top Quality RAK . . .



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At Rock Bottom PRICE!

6 feet Multi-Bay IMRAK at £27.1.8 per bay. *And* there is a Quantity Discount reduction to £25.9.2 each by the 100.

Complete six-bay rak as illustrated with hinged and quick release rear doors and detachable side panels—only £169.0.11. Fitted with strong yet elegant side doors on 'lift-off' concealed hinges—£174.18.3.

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Imhofs new Imrak International Rak is a completely universal flexible rack system. It can carry British, American and Continental fixings. It packs flat for easy storage or transportation. There are five standard types, each made in four different heights and four different plan sizes—a choice of 80 different standard racks in this new series! There is a choice of normal front panels, one piece front panel or recessed front panels with removable door. Skilful design ensures an elegance of appearance that enhances but does not dominate the instruments. The standard hammertone finishes are ideal for reliability and long service; other finishes are available to special order.

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For use on gas/air.

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air operated
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for controlling flow of fuel fed by ring main systems.

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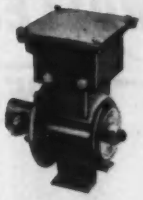

3-WAY AIR VALVE
ADMIRALTY pattern
otherwise as TW/HP/AC.
Size ¼", ⅜", ½" B.S.P

WE KNOW THE ANSWERS

3-WAY VALVE diaphragm operated suitable for use on hydrogen at pressures up to 22,000 p.s.i.
Size ⅛", ¼", ⅜" B.S.P.

BLACK
AUTOMATIC CONTROLS LTD

DIFFERENTIAL PRESSURE SWITCH
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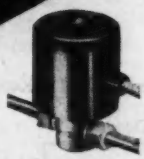
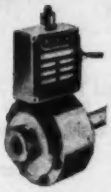
Temperature 250°C.



FUEL OIL VALVE
Size ¼"—½" B.S.P.
Pressures up to 500 p.s.i.g.



FLOW SWITCH
Standard model size
¼" B.S.P.—½" B.S.P.
Other models in sizes up to 14"

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Size ¼"—½" B.S.P. High pressure, high viscosity

The range of solenoid and diaphragm operated valves and pressure switches developed by Black Automatic Controls is finding a rapidly increasing acceptance in modern industry, including the missile and nuclear energy fields.

Whatever your application, whatever the medium or operating temperatures, if it can be made Blacks can make it. Let us know your problems. Purpose made or standard we could well be of assistance to you. Send us full details of your applications and we can put forward suitable recommendations.

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Solid state electronics for Solid reliability

The RACAL COMPUTING COUNTER CONTROLLER

TYPE SA.501A

Using only ferrite core and transistor techniques in the counting circuits —

The Racal type SA.501A is a unique fully transistorized Universal Counter Timer utilizing transistor/ferrite core techniques throughout. Ideally suited for industrial and laboratory applications alike, the instrument incorporates a fully variable digital time-base and in-line display.

FEATURES

- ★ Frequency Measurement 0—110 Kc/s
- ★ In-line Display
- ★ Variable Digital Timebase
- ★ Transistor/Ferrite Core Techniques
- ★ Operates Remote Readout or Digital Printer

A modified version of the SA.501A is available designed specially as an Electronic Tachometer, for the direct measurement of engine speeds etc. This instrument, the Racal type SA.502 incorporates the above features in a compact portable, battery operated equipment. For further details on these instruments please write to:—

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Bracknell, Berkshire, England Telephone: Bracknell 941 Cables/Grams: Racal Bracknell Berks.

Here is a 12v. stabilized d.c. supply at 4 amps!

How to obtain high current constant voltage D.C. supplies?

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These new D.C. Supply Units . . . .

- Provide HIGH CURRENT OUTPUT AT LOW COST
- Are SMALL IN SIZE AND WEIGHT FOR VA OUTPUT
- Have HIGH ENERGY RESERVOIR, thus are suitable for pulse, intermittent or variable loads
- Operate with HIGH EFFICIENCY

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DC.6	24 volts	5.00 amps	£30
DC.7	48 volts	1.00 amp	£20
DC.8	48 volts	4.00 amps	£35

Advance CONSTANT VOLTAGE

D.C. POWER SUPPLIES

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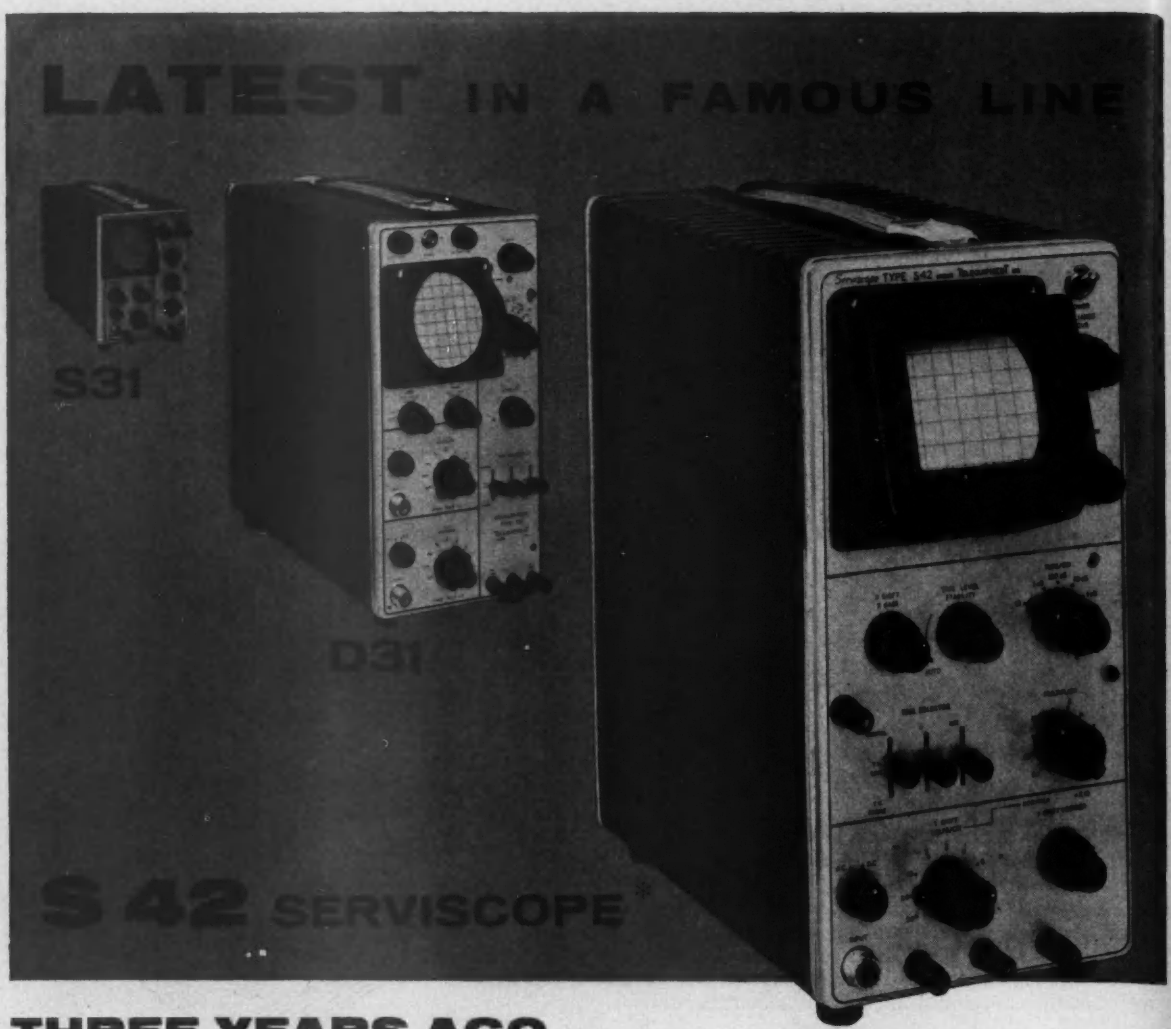

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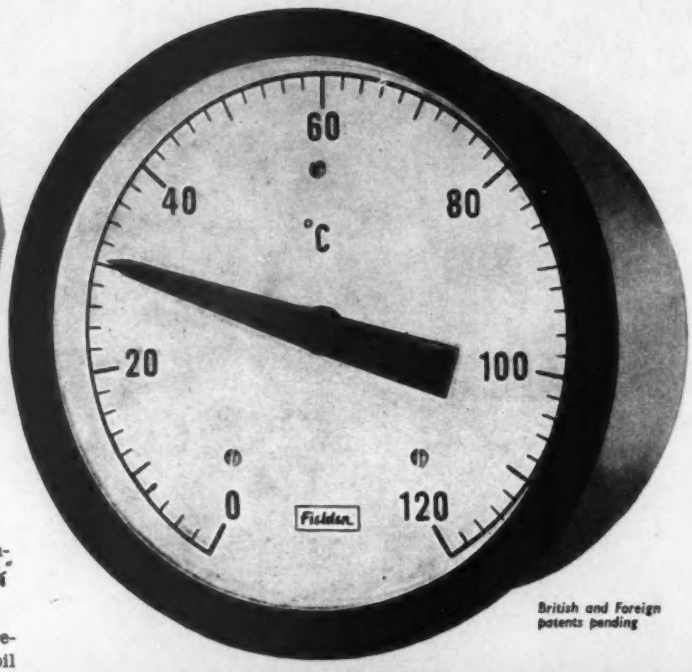

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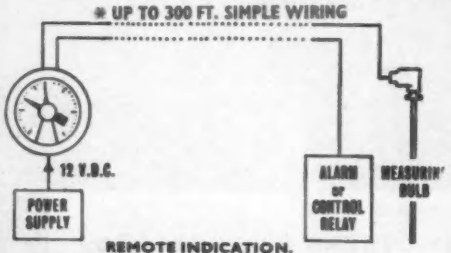

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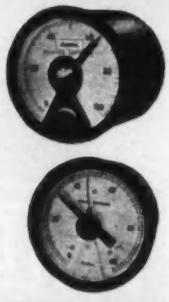

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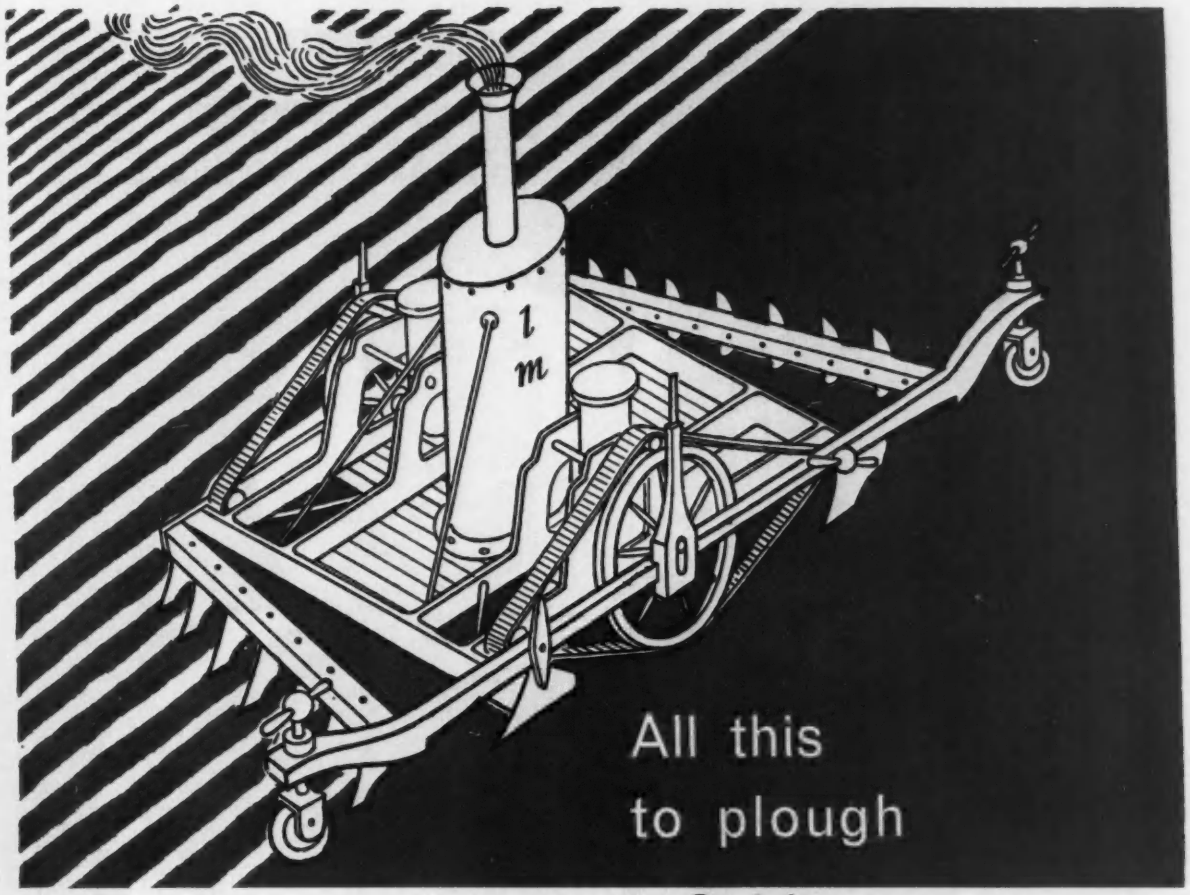

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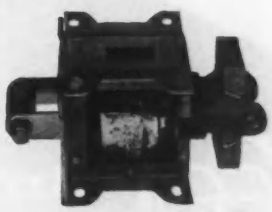

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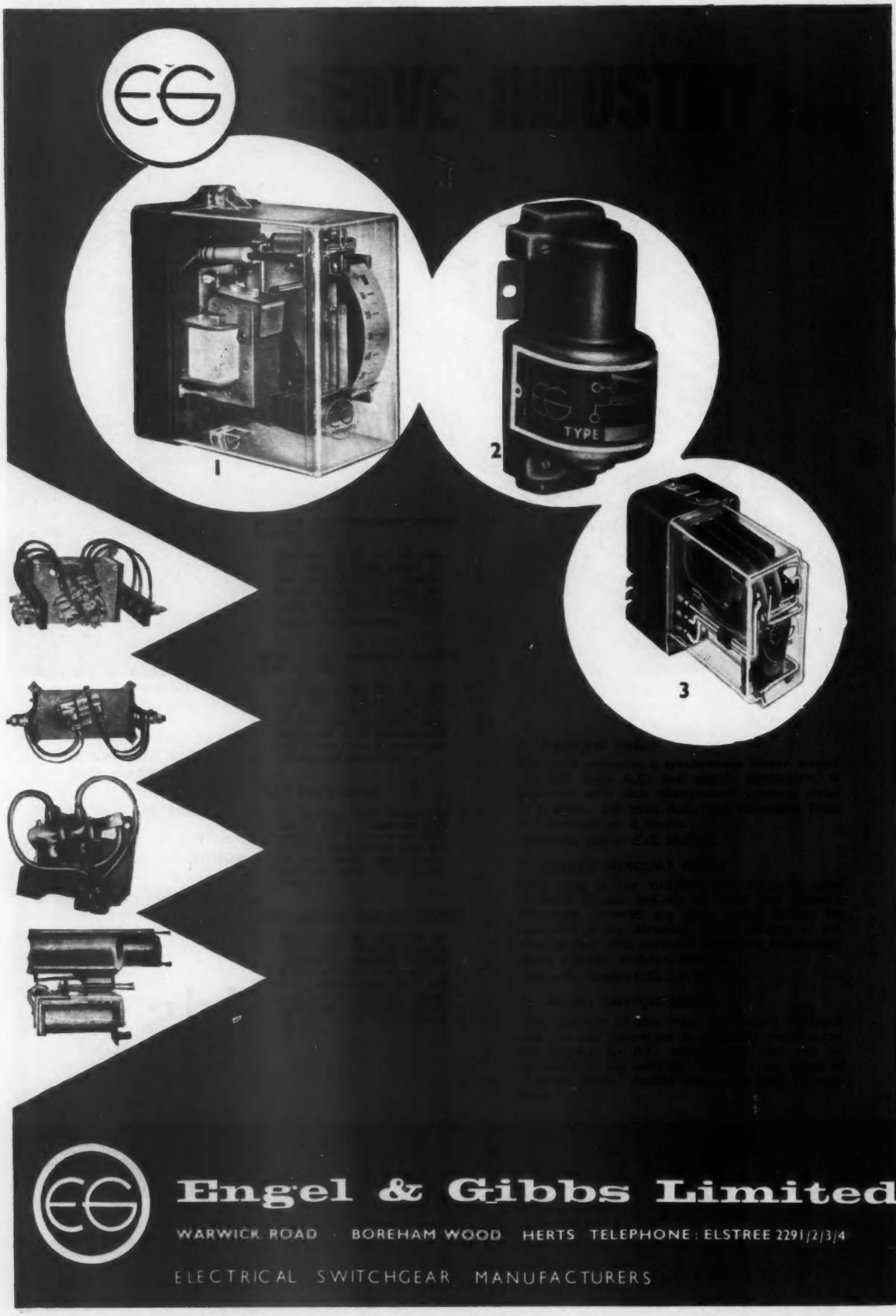

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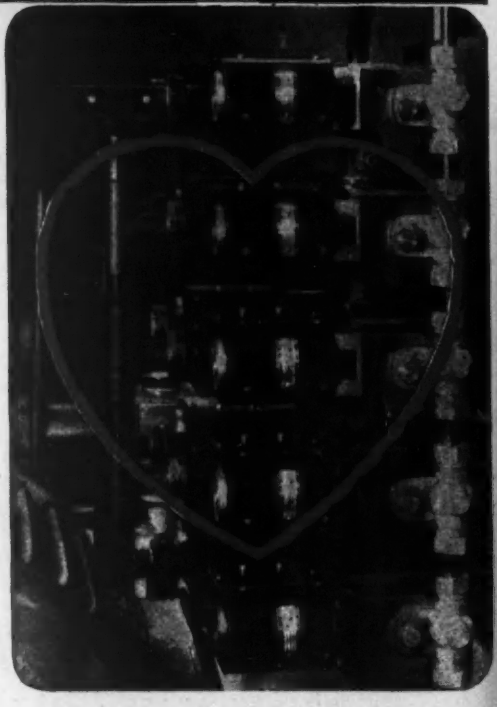
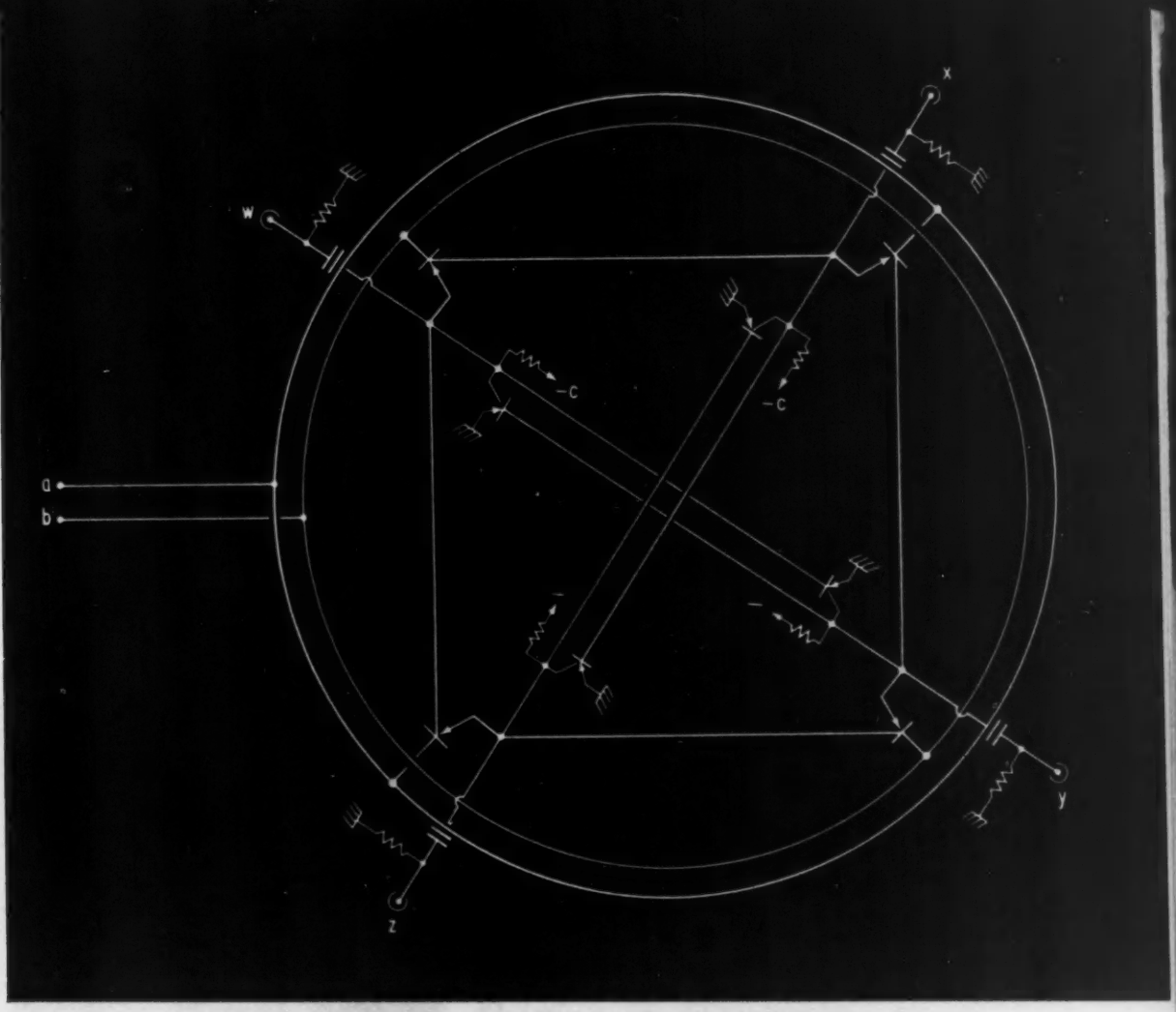
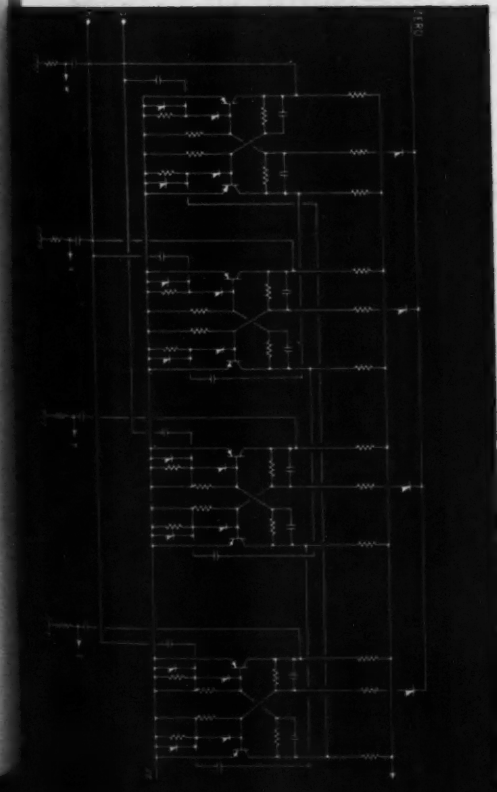


Bank of Westool Solenoids operating hydraulic valves. Photograph by courtesy of Towler Brothers Ltd, Leeds.

TIS. 139



YOU KNOW WHICH IS BETTER!



Just by looking at these two circuits, the experienced designer knows which is better. He knows that the simple, straightforward circuit shown above, incorporating Semiconductors' SB Transistors, offers real performance-improving, cost-saving advantages.

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- ✱ If you want parameter variation immunity . . .

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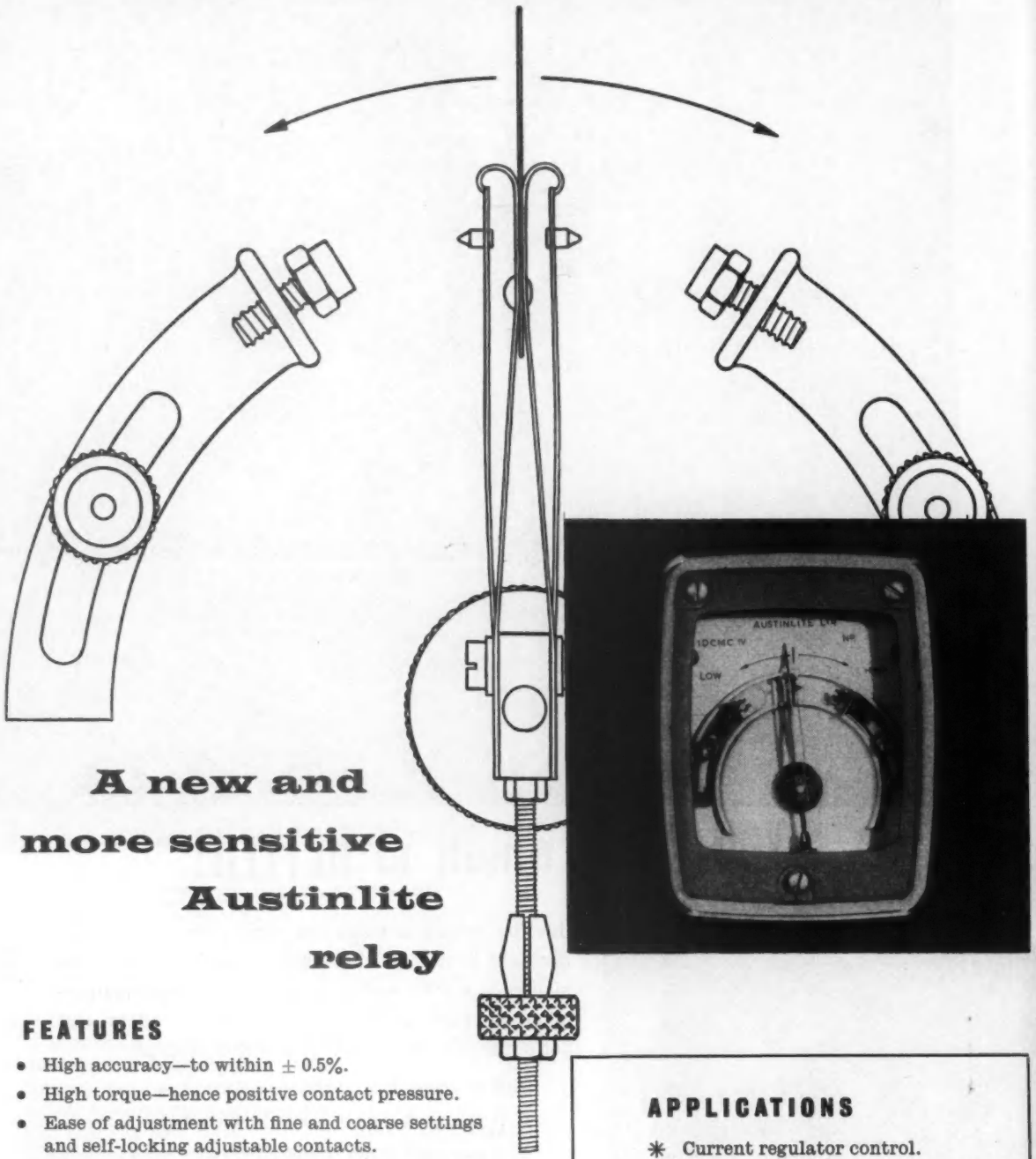

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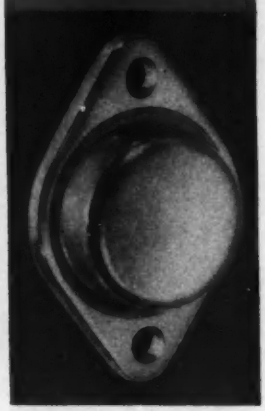
OC28

A NEW TRANSISTOR DESIGNED FOR D.C. CONVERTER APPLICATIONS



Progress in one of the most promising fields of transistor application—d.c. converters—has been delayed not by a shortage of power transistors, but by transistor avalanche breakdown caused by the simultaneous heavy currents and high voltages encountered in inductive circuits.

Now, after extensive application work and customer consultation, Mullard introduce the OC28—a transistor designed and tested for use in 28-volt d.c. converter and similar applications where inductive loads are employed.

The OC28 is dynamically tested to withstand 60 volts at 0.5 amp and 60 volts at 6 amps. This testing is additional to the normal static voltage ratings of 80 volts collector to base and 60 volts collector to emitter under cut-off conditions.

The assurance of specially controlled and specified avalanche breakdown characteristics broadens scope for the design of nominal 24 volt power converters, even where the actual supply voltage rises on occasion to 30 volts or more. For operation in self-oscillating circuits a tight control on current gain is exercised.

In static and mobile equipments—in road, rail, sea and air-borne applications—the generation of high voltage for lighting, instrumentation, communication and control is now possible. The performance and small size attainable are exemplified by a pair of OC28's mounted on a folded blackened $\frac{1}{8}$ in. thick copper plate of area $3\frac{3}{4}$ in. x 14 in. Operated from a 28 volt supply in a push-pull circuit utilising two small transformers, they will deliver 100 watts at 195 volts d.c. with an overall efficiency of 86% in ambient temperatures up to 80°C.

Please write on your company letterhead for data sheets and any further information on the OC28.

OC28

Abridged Data

V_{cb} max. (I_e=0)	−80V
V_{ce} max. (cut-off)	−60V
V_{ce} max. (I_c=0.5A)	−60V
V_{ce} max. (I_c=6A)	−60V
I_c max.	6A
P_{tot} max. at 45°C mounting base temperature	30W
T_j max. (continuous rating)	90°C
T_j max. (intermittent rating, 200 hours max.)	100°C
$\bar{\alpha}'$ (at V_c = −1V, I_c=1A)	20 to 55
$\bar{\alpha}'$ (at V_c = −1V, I_c=6A)	15 to 30

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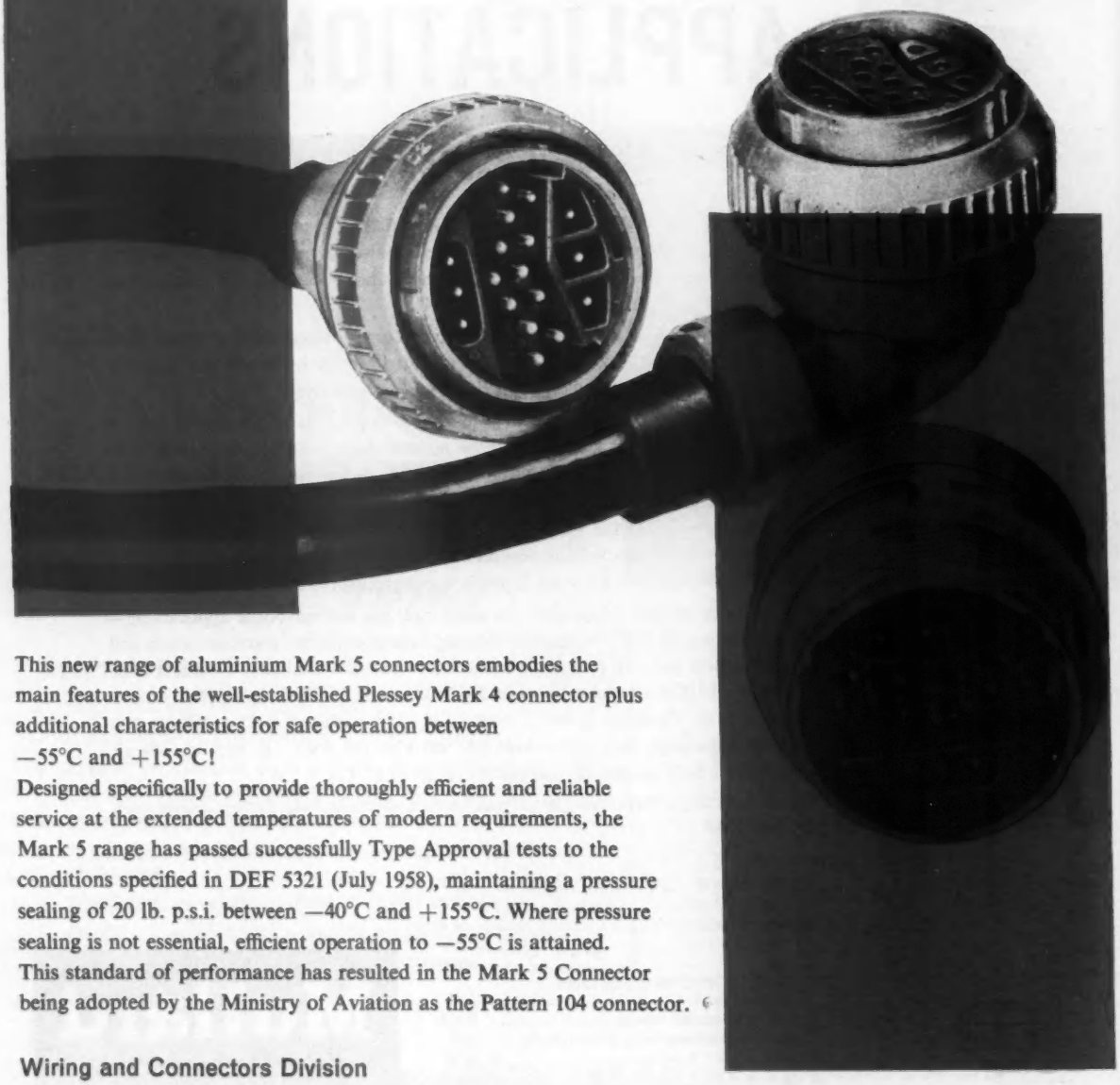
industrial semiconductors

MIS 24

from -55°C to +155°C

Plessey mark 5 connectors



This new range of aluminium Mark 5 connectors embodies the main features of the well-established Plessey Mark 4 connector plus additional characteristics for safe operation between −55°C and +155°C!

Designed specifically to provide thoroughly efficient and reliable service at the extended temperatures of modern requirements, the Mark 5 range has passed successfully Type Approval tests to the conditions specified in DEF 5321 (July 1958), maintaining a pressure sealing of 20 lb. p.s.i. between −40°C and +155°C. Where pressure sealing is not essential, efficient operation to −55°C is attained. This standard of performance has resulted in the Mark 5 Connector being adopted by the Ministry of Aviation as the Pattern 104 connector.

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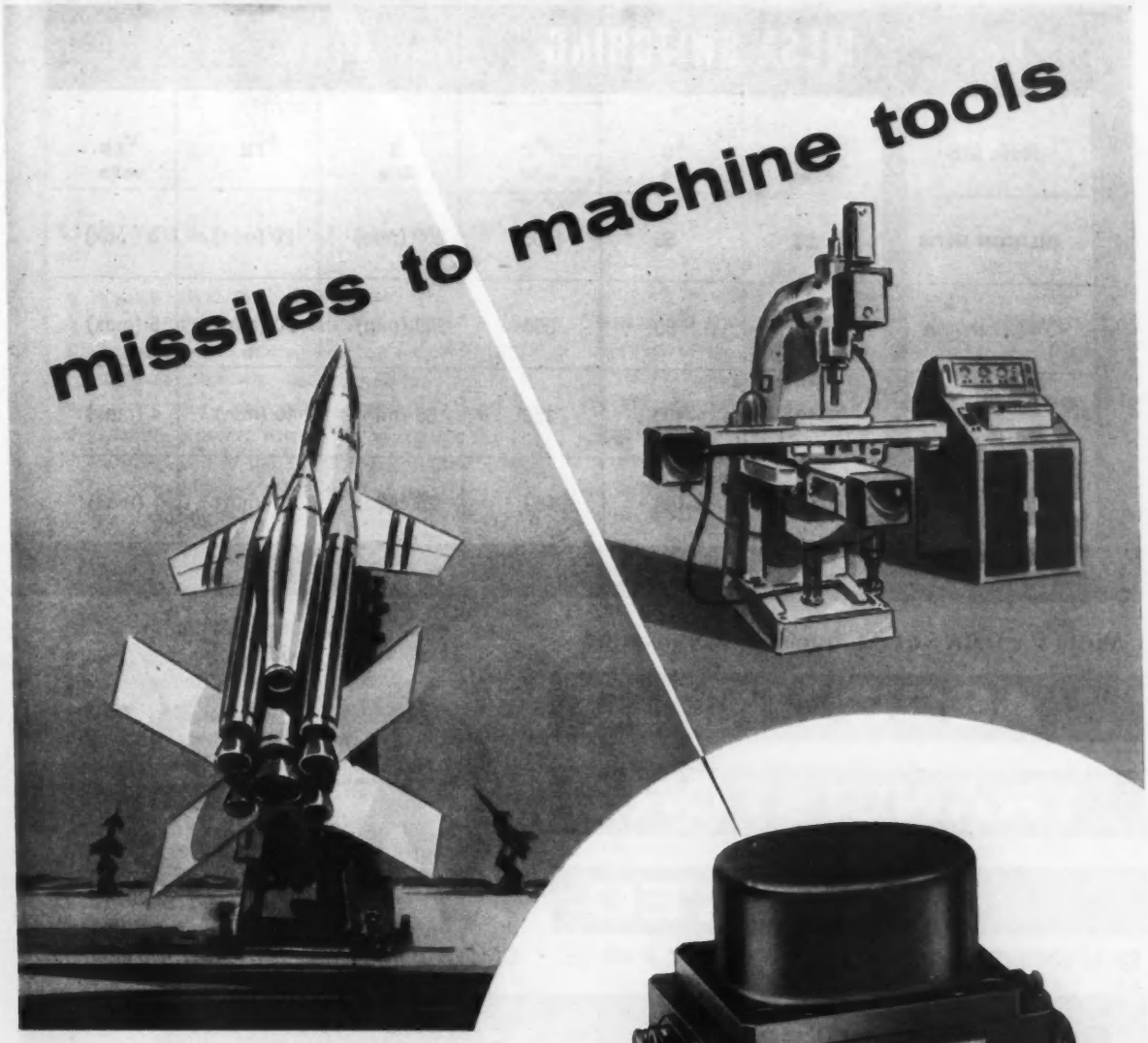

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SILICON 2N706	20	50	300	200 (min)	20 (min)	3 (max)
2N706A	20	50	300	200 (min)	20 (min)	5 (max)
GERMANIUM 2N1301	—12	—100	150	35 (min)	40 (min)	4 (max)
2N1300	—12	—100	150	25 (min)	30 (min)	1 (max)

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Ref: 2N398			
V_{CE} (volts)	—105	P_C (mW)	50
V_{EB} (volts)	50	Beta	20 (min)
I_C (mA)	—100	V_{CES} (volts)	—0·2

NPN SWITCHING GERMANIUM TRANSISTORS

Ref: NGS	2N1091	2N585
V_{CE} (volts)	15	24
I_C (mA)	400	200
P_C (mW)	120	120
f_α (Mc/s)	13	5
Beta	40 (min)	20 (min)

NOVEMBER 1960 VOL. 3 NO. 29 CONTROL

Gimmicks and real contributions

IN LAST NOVEMBER'S LEADER we referred lightheartedly to the difficulties of learning mathematics, and quoted a certain company's technical director who had suggested that mathematicians were deliberately fencing in their art in order to preserve some kind of mystique.

As long as the mathematicians confine themselves to manipulation of literal symbols they can go on bemusing even technical people, at least for part of the time: but many symbolic situations can be put into diagrammatic form, and, when this is done, huge and revealing rents may be torn in the camouflage netting. As every engineer knows, diagrams can help tremendously in both the interpretation and appreciation of analytical results. Graphical representation can be used either to summarize a whole position, or it can be detailed enough to yield precise information. A particular use of graphical methods is to get a qualitative 'feel' of the mathematics of a situation, and especially to appreciate the general effect of some proposed variation: such study is often much easier in terms of graphical than of literal symbols, perhaps more often in control engineering than in some other branches of technology.

The linear differential equations of control system analysis can be written to describe either a complete system or a portion of the system. In whatever way the equations are solved, whether by intelligent guessing or by applying operational calculus, the answer comes out as a function of time for some specified input disturbance. A solution as a function of time may be excellent for an original equation written to cover the complete system: but tedious work is necessary to get from the performance of individual components (expressed as time functions) to the performance of the system as a whole (expressed as a time function). The drudgery is worse if one is interested particularly in what may happen when some parameter of the system is varied.

Another way is to assume that all time functions are sinusoidal oscillations. The differential equations can then be studied in terms of frequency response, and the effect of cascading segments of the system can be found readily by multiplying, giving ultimately an overall transfer for sinusoidal oscillations. Manipulation is much easier when this method is used, and it can be made largely graphical. The facility with which it enables a designer to study the results of parameter variation makes the technique a favourite among control engineers, and it is entirely adequate for systems that are not too complicated or unusual.

The principle of sinusoidal analysis can be extended to 'complex frequency' analysis, using signals that represent, in general, sinusoidal oscillations of a magnitude that varies exponentially with time. Complex frequency analysis helps to close the gap between frequency and time responses, and it can also give much more information about situations that are complicated or unusual. Furthermore, it can be quite closely linked with the employment of operational calculus in system analysis.

Complex frequency analysis is applied to control systems as the *root locus method*, which is particularly attractive because of its heavy reliance on graphical interpretation. This can provide a strong qualitative grasp of the mathematical situation—important when one has to consider the consequences of some proposed change, or to indicate how to approach a required result.

Though its power would seem to demand recognition, the root locus method is still not widely-enough known or practised. We are therefore glad to publish a new series of articles by Dr P. F. Blackman of Imperial College; beginning this month on page 102, it is an excellent exposition.

While on the subject of mathematical expositions, it is worth drawing attention also to another article in this issue. A report by G. M. E. Williams in *Control* last May provoked a good deal of interest at the time, and since then the Ifac Congress in Moscow has led a great many more control engineers to wonder whether the theory of invariance is another 'true but trivial' gimmick, or whether it is a real contribution to the art. Up to now there has been an absence of English-language literature on the subject, but on page 96 of this issue readers will find the result of a special study undertaken for *Control* by L. Finkelstein of Northampton C.A.T. Next month we are publishing a contribution by Professor A. G. Ivakhnenko of Kiev, acknowledged to be perhaps the world's most successful practical interpreter of the theory; he will give a few examples of its application, and after that some British readers may become as vocal and disputatious about it as their Soviet counterparts!

LETTERS to the EDITOR

Laplace transforms—how low can you get?

SIR: I am extremely glad to see in the August issue of *Control* that Messrs. Head and Mayo of the B.B.C. Research Department commit themselves to full support of the *s*-multiplied Laplace transform, thereby endorsing the main point of my article of the previous month. They also raised, however, two other quite separate issues, namely

(i) Is s a number or an operator?
(ii) What is the proper formulation of the connection between differentiating $f(t)$ and multiplying $\bar{f}(s)$ by s?

In attempting to find some indication of the correct answer to their first question, it is necessary to distinguish between what is meant by operational calculus and what is meant by transform calculus. When we write D for d/dt, D is an operator meaning 'carry out the operation of differentiation with respect to time upon what follows'. It remains to be shown later that in certain circumstances D can be treated as an algebraic entity. I can, if I like, describe the operation of squaring a function and subtraction of 6 by some symbol, say X: X is thus an operator, and $Xf(t) = (f)^2 - 6$. I can also define an operator £ meaning 'integrate from $0+$ to t with respect to t the product of e^{-st} and some one-sided time function, and multiply the result by s'. Adopting this approach, £ is clearly an operator. This, however, is very different from suggesting that s is an operator. In the Laplace transform, s is a complex number; it is in fact a point on the complex s-plane, $\sigma + j\omega$. It remains to be shown later that performing the operation of differentiation in the time domain bears a special relationship to multiplying by the complex number s in the complex s-plane. If the distinction between the operational and the transform approach is borne in mind, there should be no danger of confusion as to what s is.

It is, however, the suggestion by Head and Mayo in connection with the second point that I find specially alarming. I am in complete agreement that an alternative (though I cannot accept 'preferable') method of defining the integral ${}_a\int^t f(x)dx$ is ${}_{-\infty}\int^t f(x)u_o(x-a)dx$, where u_o denotes the Heaviside unit step function. To go on to suggest, however, that by making the lower limit of integration $-\infty$ (or indeed any negative value) in the Laplace integral (I quote) "differentiation of $h(t)$ n times will multiply the transform $f(s)$ by s^n . . . without any additional terms whatever," is plainly absurd. Multiplication of the transform by s^n will give in the time domain the n'th differential of the product $h(t)u_o(t)$, i.e., expanded by Leibnitz' theorem,

$$h(t)D^n u_o(t) + nDh(t)D^{n-1}u_o(t) + [n(n-1)/2!]D^2h(t)D^{n-2}u_o(t) + \ldots,$$

to which Messers Head and Mayo are very welcome, but which might well daunt many enthusiasts.

It is, of course, important to decide whether or not we are going to confine ourselves to Reimann integrals. If we are, and I suggest that the majority of engineers will not want to stray into the statistical world of Stieltjes, then the use of $0+$ as a convention to indicate that the lower limit of integration is approached from the right is perfectly correct. An impluso at the origin can be regarded, for example, as a rectangular pulse of height $1/t$ and width t, with $t \to 0$. The normal method of treating improper integrals can be adopted, and, provided that care is taken with regard to the order in which the limiting processes are taken, the correct result is obtained, namely that the unit impulse $u_1(t) \supset s$. Further, in many problems of electrical circuitry where a circuit response is required when a switch is operated, the relevant initial conditions are not the pre-switching conditions at $0-$, nor the conditions at 0 (whatever they may be), but the conditions immediately after the operation of the switch, i.e. the conditions at $0+$.

The argument from the rifle and the cartridge is clearly completely invalid, since by considering the part of the plane to the right hand side of the vertical axis to represent the cartridge the opposite result is reached to that intended by the writers.

I would like finally to re-affirm my belief in the desirability of the *s*-multiplied Laplace transforms which Messrs Head and Mayo also support. It is most unfortunate that so many books on the theory of control have been written by engineers who have carried on the tradition of the non-*s*-multiplied transform without consulting their mathematical colleagues who would (or should) have offered different advice. It is very much to be hoped that this will be righted in future text-books, and that authors of books not adhering to the dimensionally consistent form will amend future reprintings of their publications.

R.A.F. Technical College H. GRAHAM FLEGG

Automatic mix-up

SIR: In the June issue of *Control* a press release from Brook Motors Ltd., Huddersfield, appeared on p. 128.

It was erroneously stated in the description that the panel was installed at Messrs. J. Dawson Fawcett of Darlington and that mixers were supplied by Messrs. Goodwin Barsby.

The description should have read as follows: "Tarred macadam for roads is now mixed under automatic control by the Mountsorrel Tarred Macadam Co. Ltd., at their Enderby Quarry, Leicestershire. The complete mixing unit was supplied by Messrs. J. Dawson Fawcett (Darlington) Ltd."

Brook Motors Ltd. regret their error in description and offer their apologies to Messrs. J. Dawson Fawcett (Darlington) Ltd., and to the Mountsorrel Tarred Macadam Co. Ltd., for any inconvenience this may have caused.

Brook Motors Ltd. F. HALL

• . . . *and apologies to our readers!*—ED.

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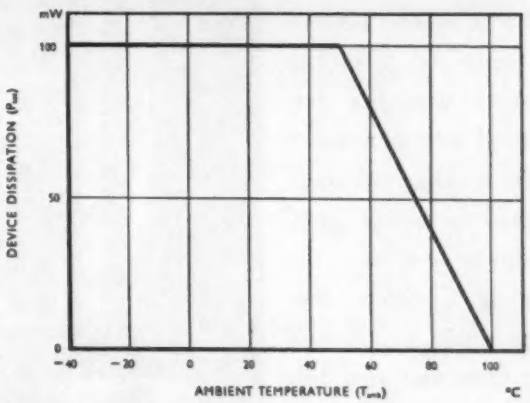

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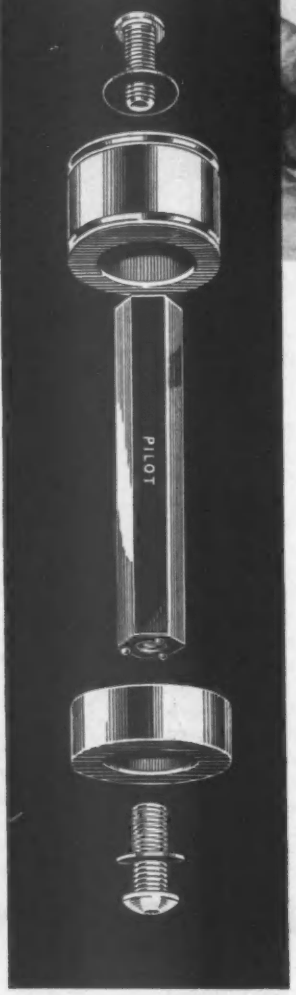

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VIEWPOINT

Dr J. H. Westcott, Reader in Control Engineering at Imperial College, and *Control's* systems consultant, thinks it about time we had an Automatic Control Research Establishment, to provide a . . .

FOCUS FOR RESEARCH

May I start by making two observations; neither of them particularly flattering to our national self-esteem: (1) that we are members of a small nation and so must make the very best of what means we can command, and (2) that attempting to maintain fifty million souls on this small island on the basis of industrial exports and services is not necessarily a working proposition.

I believe that we can make a very tolerable success of our situation provided we go about it in a businesslike manner. An essential part, I should hope, of that businesslike manner is to take mechanization in the modern sense seriously. Seriously, that is, in the intellectual as well as practical sense.

An important problem is how to provide a proper environment for prospective control engineers required to face future developments that are inscrutable. The scope of these developments, one may be sure, will be very broad indeed and may be concerned with any sphere of engineering activity. Problems of systems engineering are becoming so involved and specialized that no man can be expert enough to cover the whole, and such projects have to be tackled by a group of contributing experts.

It is, of course, true that by patient and tolerant co-operation between experts a number of remarkable developments have been brought to fruition, but this has only occurred where the co-operating experts have associated sufficiently closely to get an insight into the motives and difficulties of their colleagues.

Much as I should like to discuss the universities' educational problem in connexion with automatic control, I leave this for another occasion. It is relevant to recall, however, that the total output from my own college of fully qualified post-graduate course students in automatic control is between ten and twenty a year, and what I am concerned to inquire here is what happens to these valuable few, and do they have the opportunity to give of their best? I believe not.

The crux of the matter is our research effort: these men are the raw material of research. The rate of advance in automatic control is gathering speed; it is already often difficult to keep up with the latest position. In fact, assessing the true position is half the battle in deciding where to put effort to greatest effect. 'Keeping in touch' is vitally important, but in Britain the fraternity is all too thinly spread over universities, research associations and industry generally.

This is the age of large research teams working on major projects in big laboratories. We have them in atomic energy research and in aeronautical research. These studies require expensive apparatus and teams of a certain size in order to be viable. This is the way to success. Atomic energy and aeronautical research, while certainly important, are not vital to our economic well-being. Automatic control is. So why do we not have an establishment for automatic control—The Automatic Control Research Establishment (A.C.R.E.)?

There are reasons why this does not exist already. In atomic energy, attention can be focused on the practical device: the atomic reactor itself. Similarly, in aeronautical research attention can be focused on the aircraft. Automatic control has become an important aspect of both of them but it also has important implications for practically every manufacturing or process industry. It is a much more diffuse affair, and consequently calls for much greater skill in organization and implementation. It constitutes a much more serious challenge, and is, I maintain, much more potentially fruitful industrially speaking than the other cases I have cited.

This being the case I think it all the more important to have a substantial focus for this activity. I should like to see an organization modelled on The Aeronautical Research Council, but also having a close connexion with the universities. Apparatus should be provided on a scale to enable it to do pioneering research, while co-operation with industry would be essential to success. Suggestions along these lines have been mooted recently from various quarters, but little action has been taken.

Can we afford *not* to make the best use of our human resources in this field?

J. H. Westcott.

This excellent display established west Germany's Interkama as a serious rival to our own cramped I.E.A. Exhibition, and symbolized an industry that is 'shining bright and new'

Interkama in Düsseldorf

by **K. C. GARNER**, B.SC.(ENG.), A.M.I.E.E., A.F.R.AE.S.
College of Aeronautics, Cranfield

THE FIRST DUTY OF A CORRESPONDENT IS TO PLACE THIS exhibition and congress on instrumentation and automation in some sort of perspective with similar activities elsewhere, and perhaps the best way to do this is by briefly summarizing the status of the related industry of the German Federal Republic. In west Germany there are about 250 firms with 70,000 employees specializing in this field; and, similarly to the pattern elsewhere, there are one or two giants like Siemens-Schuckertwerke Aktiengesellschaft, and Allgemeine Elektrizitäts-Gesellschaft (A.E.G.) while the vast majority employ less than 1000 employees. The annual capacity runs at more than 1·1 billion DM, of which 30% is directly exported, with a great deal more exported as built-in components on foreign-based German process plants. In home industries the instrumentation runs at 5% of the total investment for power plants, rather more for steel, and at least 10–20% for chemical plants. These figures in themselves are not significant unless it is realized that the major proportion of west German industry is shining bright and new. This means that the very latest instrumentation is going in with very little opposition from conservative management or prejudiced labour. This I regard as the true message of Interkama.

The exhibition itself was superb in its presentation at the Ehrenhof pavilions, covering some 39,000 m² and housing 470 stands, 280 of which were German, and the rest from western Europe, the U.K. and the U.S.A. Only two, e.g. Hungary and eastern Germany, were present from the communist camp. These figures show an increase in size of over 30% since 1957, and judging from the literature of the 1957 Interkama, the intervening three years have brought with them a considerable advance in west-German technology. This advance, while being rapid, has not, in my opinion, brought them quite up to British and American standards in any major field. Nevertheless, the salient feature of the exhibition was the tremendous enthusiasm, and sometimes even impatience, to utilize the very latest techniques in their new industries.

Electronic control systems, whether analogue or digital, seem to be accepted without question if there is no obvious economic disadvantage, or any overriding safety requirement. Thus pneumatics has taken a definite second place in German control philosophy. The emphasis throughout is on more and more solid-state digital control, with the obvious advantages of programming procedures and easy, effective, data-gathering.

Having only limited space I can include only a few of the exhibits which merit attention, although these represent a tiny fraction of this vast and glittering exhibition.

Logic systems

Undoubtedly the field of major interest is the application of logic circuits to production control, and to automatic control and supervision of servo-mechanical and process systems. Several firms had demonstrations of such systems, notably Siemens (Simatic), A.E.G. (Logistat), which have been shown previously in less advanced form, and a new and extremely compact system developed by the Belgian firm Ateliers de Constructions Electriques de Charleroi, called Logacec. Each of these systems is built from unit solid-state logic circuits providing AND, OR, NOT and time-delay functions etc. The first two systems mentioned above have each function in a plug-in module, and the appropriate ones are inter-

connected in a plugged frame. In the Belgian system one modular unit contains a variety of functions interconnected across external terminals to provide the desired switching system. All these systems are in industrial operation on various plants in Germany and Belgium, and Logacec pilot schemes are being used by Renault to control some of their transfer machines. A.C.E.C. also combine a range of their units into a so-called 'logic simulator', which, by utilizing easy patching facilities, makes complicated logical systems evaluable, especially in conjunction with an analogue computer to simulate the appropriate dynamic components in the overall system.

All these logic systems can be programmed either by interconnexion or by standard read-in equipment.

Siemens-Halske AG provided two very convincing working demonstrations of combined analogue-digital control servo-systems. The first was a completely automatic rolling-mill screw-down control, programmed from a ferrite-core memory from data either manually read in or from punched cards. The control console provides all the usual manual controls, in addition to keyboard controls for initial absolute setting and subsequent manual incremental settings of the roller spacings for each pass. The system is accurate to 0·1%, with numerical read-outs for visual monitoring and, if required, data-logging. Complete freedom of choice between programmed control, or digital or analogue manual control, is available at any stage in the rolling operation, so that mill-operator experience can be utilized if the temperature of the billet is wrong, or if the billet becomes skewed relative to the rolls.

The second system demonstrated a speed control relating the speed ratio of two independent feed rollers of a paper mill. Again all the manual controls normal to such a plant are present, and the fine digital control co-ordinates the speed ratio. This is done by counting the cycles from a.c. tachometers coupled to each drive, and the difference between the counts is converted again to analogue form. This signal is compared with a reference signal which determines the desired speed ratio. An accuracy of better than 0·1% is achieved.

Process instrumentation

In the field of industrial process instrumentation there was truly an immense range of controllers, recorders, monitors, and transducers, of inconceivable variety, although (apart from unfamiliar legends) very little novelty. Here and there, however, a new item appeared, the most unexpected perhaps being the new pneumatic three-term controller Minipid by J. C. Eckardt A.G. This is, without question, one of the neatest permutations of four bellows and flapper-nozzle assembly so far devised, and very much in keeping with German mechanical engineering tradition. It consists of a ring carried by a cruciform arrangement of four bellows anchored at a central spigot. An opposite pair measure the difference between the set point and the measured value, while the orthogonal pair, through their respective restrictors, provide the reset and derivative terms. Proportional band is set by a pointer which constrains the ring to rock about a point on its periphery in relation to the first two bellows. This firm also manufactures a novel proportional manometer gauge with transistorized alarm and switching facilities, as well as a wide range of electronic (thermionic) three-term controllers and recorders etc.

Analogue computers

Analogue computers were naturally on exhibition, with Electronic Associates Inc. (Pace) well to the fore. They were showing the Adios automatic digital input-output system, which provides tape-programming coefficients and read-out facilities. This installation is used already by the C.E.G.B., A.E.I. and U.K.A.E.A. in the U.K. and by two institutes in Germany. Euratom have one on order. Yet this was apparently the first public showing.

Many other exhibitors showed analogue computers, usually completely transistorized. The more notable ones were Telefunken, Beckman, Solartron G.m.b.H., and Brown Boverie & Cie A.G. with both large and desk-type instruments. The latter firm also have a 'Logical computer' similar to the A.C.E.C. version. Güttinger of Switzerland produced a twelve-amplifier desk type, and also a specialized computer called Statistic for production control. A.E.G. provided a complete range of transistorized computers and showed for the first time a new frequency-response analyser, with a range 0·1 c/s to 1·110 kc/s.

Solartron G.m.b.H., have also introduced a new crystal-controlled signal generator from 50 kc/s to 500 Mc/s using b.f.o techniques, which, with standard plug-in units, can provide a wide range of modulated waveforms, both amplitude and frequency, with precision attenuators, and frequency-comparison sub-units. This instrument will undoubtedly find many applications in the v.h.f. and telemetry fields in the near future.

Tragic British shadow

The British stand was tragically a mere shadow of our potential. It was dull and cramped and altogether uninspired, with the minor irritation, for the local visitors, that most of the staff were monolingual Englishmen, although adequate interpreters were present; this was in contrast to the passable English spoken by at least a third of the rest of the exhibition personnel.

Interkama will, after this excellent show, become a major event in the control field, seriously rivalling our own more cramped A.E.I. Exhibition. Düsseldorf was well chosen as a setting, with an airport only ten minutes from the centre of this friendly and attractive modern city of boulevards, glittering shops, parks and lakes.

In conclusion, let me reiterate that while the techniques and devices are no better than those available in Britain, the sheer enthusiasm for applying the fruits of this technology is truly impressive.

A report on the fifteenth Annual Conference and Exhibit of the Instrument Society of America, the theme of which was . . .

Progress through instrumentation

by **REGINALD MEDLOCK**
George Kent Ltd

THE 1960 ANNUAL CONFERENCE AND EXHIBIT OF THE I.S.A. took place in the New York Coliseum, where some 300 manufacturers exhibited, 200 papers were read and 16,000 visitors were registered. Many of the technical sessions were concurrent in time; in consequence, one person was limited to attending not more than 9% of the technical sessions, and this often led to mental conflict when two or more interesting papers were read at the same time. It is a pity that some multiplexing or time sharing system has not been invented to resolve the listener's dilemma.

The Conference opened in good American style with a demonstration of a miniature f.m. radio transmitter strapped close to the heart of a handsome young naval officer. The detected heart beats were displayed on a large oscilloscope and were plainly heard from 'woofer' speakers—all of which became heavily overmodulated when an attractive blonde held the officer's hand.

Having thus had our fun, we were started on the serious part of the business with the three 'keynote'-session papers on progress through instrumentation in the petroleum industry, in the power industry, and in the missile and space age.

THE CONFERENCE

A large number of papers was concerned with instrumentation for oceanography. Interest in this subject is very great at the moment on account of its military importance, and consideration is being given to the formation of a separate section or group.

There were two whole sessions dealing with strain gauges. Since the first commercial development of these gauges in 1929 considerable strides have been made, due in part to space and missile requirements. Slowly, the strain gauge is entering the process field, a specific example being a refinery which started up over a year ago, which used strain gauges for most measurements except temperature. The maintenance required was reported to be less than for pneumatic or other electric systems.

Commercial-type semiconductor strain gauges have been developed having gauge factors of 130 compared with approximately 2 for wire gauges. Semiconductor types of gauge have been in use since 1958, but the early ones had undesirable characteristics. For example, the gauge factor and the initial resistance varied considerably with temperature, and they were fragile and non-linear. Recent research has shown that by increasing the 'doping' (an American term) to about 10^{20} boron atoms per cm^3 of silicon, these disadvantages can be greatly reduced, although there is also some reduction of gauge factor. Nevertheless it still remains some sixty times that of wire gauges.

Computer control

In the process field the main interest was in computer control. British visitors worked particularly hard to get specific information on how far this area of activity had progressed in the U.S.A.—how many had been ordered, how many were working, how well, and what industries were asking for them. It was not easy to obtain the answers. Often when answers were obtained they were unintentionally misleading, because they referred to all computers used in the process indus-

tries, including those used for 'off line' computation, data processing and alarm systems.

It would appear that there are about six 'on-line' controlling computers claimed to be actually working in the U.S.A. The number of systems actually ordered is considerably more, and, at a cost of around £100,000 per system exclusive of basic instrumentation and control, the interest is not only technical. One computer manufacturer has on order twenty systems for the U.S.A. alone. In reply to a question, the author of one paper analysed by industry the applications known by him to have been ordered on his own company. The figures quoted were:

Utilities	8 sets
Power Stations (for automatic starting-up and shutting-down procedures)	8 sets
Steel Works	7 sets
Power Stations (data processing and control)	3 sets
Chemical Plant	3 sets

The number of applications for the automatic starting-up and shutting-down of boilers and turbines in power stations seems to be high in terms of the economic and other advantages to be derived from such an application.

It was interesting to speak to one computer manufacturer who had recently visited the U.K. and who was disappointed to find a lack of interest in this field. (It may, of course, have been only a lack of interest in his computer.)

Sufficient operating experience had been obtained in commissioning computer control systems to provide material for one paper on the subject. Previously much has been written of a speculative nature, with surprisingly little publication of actual performance and results.

The interest in computer control seemed to be the outstanding feature of this year's I.S.A. show. Two years ago in Philadelphia one of the technical sessions dealing with this subject organized a census of interest, which showed that about 80% of those attending the session were affiliated to instrument and computer manufacturers, and the remaining 20% were from user industries. This year the percentages were approximately reversed.

As an anticlimax to this potential multi-million dollar equipment with its enormous technical complexity, a paper was read by B. M. Horton which described such elegant and simple equipment that it charmed the audience, and incidentally won for the author the Arnold O. Beckman Award of 1000 dollars for 'the most important technological contribution to the conception and implementation of a new principle of instrument design, development or application'. Horton's paper was entitled 'Pure fluid amplifiers' and described an amplifier device which operated, without mechanical movement, by means of fluid stream interaction.* In its simplest form a parallel jet of liquid or gas was deflected by another jet impinging on it at right angles. The deflexion of the kinetic energy of the jet provided the means of amplification. By using positive and negative feedback effects, the device could be used as a bi-stable flip-flop or as a continuous oscillator.

* See also 'Look at America', in our August 1960 issue, p. 111.—EDITOR.

THE EXHIBITION

In this section of the report some general impressions will be given together with a few notes on some particularly interesting instruments.

In comparison with previous exhibitions, the 1960 Exhibition appeared to be less well attended and to show rather less new equipment. The emphasis was on consolidation of design, following the introduction of several competitive ranges of electronic measurement and control systems two years ago.

Electronic equipment was monotonously described as being 'all transistorized', and was found to have tighter packaging, printed circuitry, encapsulated modules and even micro-electronic circuits. One enthusiastic salesman pointed out that his instrument was so compact that if you tried to pour water into it there would be nowhere for it to go.

Although the big instrument firms with the well known names are expected to be first to bring out exciting new designs, there is invariably at least one small young firm each year which provides a minor sensation in design. An example was provided this year by De Var Systems Inc., formed about a year ago by a group of engineers interested in developing a new approach to electronic control systems. One of their products is a miniature electronic potentiometric recorder with some interesting technical features. The amplifier is made up of six encapsulated modules which are electrically interconnected with metal straps and screws (no plugs). It need scarcely be mentioned that the modules are 'all transistorized', including a transistor input chopper. This, with an unusual feedback and isolation circuit, provides high common mode d.c. rejection and freedom from a.c. line noise. The recorder pen is operated by a powerful torque motor which also drives a feedback inductive transformer, instead of the conventional slide-wire. The first impression was that it would be difficult to conceive a more intrinsically failproof design. As a parting shot it is pointed out that, if the mains should fail, then a self-contained nickel-cadmium battery automatically takes over and keeps the instrument working (except for the chart motor).

The victory of transistors over tubes is by no means absolute. It is interesting to find that even a large transistor manufacturer had brought out some new d.c. amplifiers incorporating mechanical choppers and thermionic valves. Another firm offered alternative amplifiers for a potentiometric recorder—the transistorized version being 100 dollars more expensive than its thermionic counterpart.

Electronic measurement and control

Fourteen exhibitors of three-term electronic controllers were counted—there may have been more—and

most of these could also offer miniature recorders and a limited range of transducers. Improvements in the last two years have been limited to small changes in circuitry and layout. There is an interesting trend towards the elimination of the 'balance' position in the auto-manual change-over switch, while still providing a 'bumpless' transfer, this now being an automatic operation.

Discussions are still proceeding on the standardization of the electrical transmission signal, and it is darkly hinted that there might be two standards, 1–5 mA and 10–50 mA d.c.

Many types of electrical transducers were shown, mainly for pressure measurement, and intended for testing and missile work rather than for process control. Two more firms have entered the electromagnetic flowmeter market, and offer equipment for fluid conductivities down to 0·05 micromho, i.e. almost in the non-electrolyte region. Solid-state quadrature suppressors for use with these flowmeters are available.

Sales of the electronic range of process measurement and control equipment were reported to be rising fairly rapidly, whilst sales of the pneumatic range remain fairly stable.

Analytical instruments

The development of practical analytical instruments is a prime necessity for successful computer control of processes. The large number of exhibits in this category suggests that this fact is widely recognized, though it is debatable whether all these exhibits are practical. Especially outstanding are analysers using the principle of gas chromatography which has enjoyed a meteoric rise to success. In the last five years, response times have been reduced from thirty minutes to as many seconds. Over the same period the equipment has assumed a robust industrial appearance which gives confidence in its future. Ancillary equipment was shown including specially adapted strip chart recorders, automatic peak selectors and improvements to devices used for finding both peak height and area.

Other analytical instruments included a new process refractometer; a flame photometer for measuring chloride ion content in boiler feed water down to 1 part in 10^{10}; a hydrocarbon analyser using a flame ionization detector; a new paramagnetic oxygen analyser with ranges from 0–0·002% up to 0–100% oxygen content (the principle involves the generation of a pulsating gas pressure by the action of a rotating magnetic field on hot and cold samples of paramagnetic gas, and the detection of the amplitude of pulsation by a sensitive condenser microphone); an ultrasonic gas bubble-in-liquid detector, which developed from an unsuccessful attempt to produce an ultrasonic flowmeter—the product was found to measure bubbles more successfully than flow; a simple analyser for dissolved oxygen in feed water, which measures the change in conductivity of the feed water resulting from the chemical reaction between oxygen in the water and metallic thallium.

Mass flow measurement

In recent years some ingenious designs of mass flowmeters have appeared. Originally they were designed for liquids, particularly aircraft fuel, but now some have been adapted for gases. These instruments measure mass flow rate directly, and are not volumetric meters corrected for density.

The B.S. & B.-G.E. meter works on the change-of-momentum principle. An impeller located in the gas stream imparts an angular momentum to the gas proportional to mass flow rate. This momentum is extracted by a turbine downstream of the impeller, the turbine thus experiencing a torque which is also proportional to mass flow rate. The torque is applied to the minor axis of a gyroscope which produces a proportional rate of precession round the major axis. This motion is transmitted to a direct-reading cyclometer totalizing the flow in weight units.

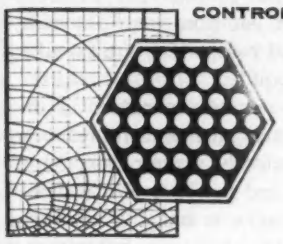
In the Decker mass flowmeter* the liquid passes through a loop of pipe which is vibrated through a small amplitude. The gyroscopic effect of the circulating fluid produces a pulsating force at the same frequency, but in another plane, and this force is directly proportional to mass flow.

The third method, employed by the Potter Aeronautical Company, simply uses two impellers each provided with a 'pick-off' probe and having differing blade angles. The impellers are coupled by a spring and are capable of relative angular displacement with respect to each other. This displacement is proportional to the flow momentum. It can be shown that a measurement of the elapsed time for the phase angle displacement to traverse a reference point is directly related to mass flow. Thus a time-interval meter used with both probes can measure mass flow and a frequency meter used with any one probe can measure volumetric flow rate.

Other physical measurements

As a conclusion to this report, the following notes are appended on a few interesting exhibits chosen at random. The first is a density-measuring equipment for slurries, similar to the well known pneumatic force-balance system of weighing the contents of a hairpin-shaped tube; but in this new instrument the tube is straight, has flexible connexions at both ends, and is supported in the centre by the feedback system. This arrangement is claimed to be more suitable for larger flows. The second is a new low-loss venturi tube which has a radiused upstream cone and a straight downstream cone. The throat tapping is taken at a point where streamline curvature gives a centrifugal head similar to that developed in the well known Dall tube. The third is an ultrasonic level detector which has two facing piezoelectric transducers, one as a transmitter and the other as a receiver. When liquid reaches the level of both probes it provides an acoustic coupling and produces a transfer of energy to the receiving probe.

* See also 'Look at America', in our August 1960 issue, p. 111.—EDITOR.



CONTROLLING NUCLEAR POWER—3

Control mechanisms for nuclear reactors have to cope with the particular difficulties and hazards caused by radio-activity. The devices evolved may not be revolutionary in principle, but they provide an elegant solution to some unique problems

PART A

Control mechanisms for nuclear reactors

by **JOHN TINDALE, M.I.MECH.E.**
Elliott Brothers (London) Ltd

THE CONTROLS DESCRIBED IN THIS ARTICLE ARE FOR GAS-cooled reactors of the type generally adopted by the C.E.G.B. for the power stations now being built or planned by the large industrial consortia. They consist of mechanisms designed to meet the power demand and to maintain the level of output. Others are designed to monitor the system to prevent the reactor from running out of control during an emergency, which otherwise might allow a dangerous critical state to arise.

DESCRIPTION OF REACTOR

The reactor under consideration consists of a steel pressure vessel in which is placed a core consisting of graphite blocks. Numbers of channels are arranged through the core and are usually vertical (Fig. 1). Gas flowing through a heat exchanger transfers heat from the reactor to a water/steam circuit which feeds the turbo-generators. From the heat exchanger to the power grid the equipment is fairly conventional, and will not be reviewed in this article.

In the channels of the graphite core are placed fissile fuel slugs in a geometric lattice pattern of such closeness as to allow critical reaction. The fast neutrons emitted by the nuclear fission of the fuel are moderated by the graphite and the energy of continuous fission is transformed into heat. Dry carbon dioxide gas is pumped through the channels in the graphite to keep the core at the required temperature, and in so doing is itself raised in temperature. The gas passes to the heat exchanger, is cooled thereby, and then returns to the core, thus completing the cycle.

If the design of a reactor is arranged so that it becomes less active as the temperature rises, this establishes one measure for safety. On the other hand if there is a greater demand for power, the gas will return at a cooler temperature to the core and could cause an unstable condition to arise, if the demand were not met by increasing the volume of coolant flowing through the reactor. Another state might arise if the normally negative temperature-coefficient were to become positive; then the requirement for quick-acting control devices would become very acute.

The coolant circuit is generally arranged so that gas enters the reactor at the bottom of the pressure vessel and flows fairly evenly through the graphite-core channels to the top, and then out to the heat exchanger. The centre of the core is the region of greatest activity, since it is bombarded from all sides; therefore the greatest flow of gas is directed to the centre.

WHAT THE CONTROLS ARE

The **neutron flux*** is constantly monitored to make sure that the designed distribution pattern is maintained for all loads (Fig. 2). This pattern is adjusted by the introduction of absorbers in channels in the graphite core between those filled with fuel elements. They are

* The *neutron flux* ϕ is actually the total distance travelled by all the free neutrons in a unit of volume per unit time. Neutron flux, multiplied by the macroscopic cross-section Σ (see p. 105, *Control*, August), gives the number of interactions per unit time (because $\phi\Sigma$ is the total travel of the neutron population (per unit time) divided by the mean individual travel). Neutron flux is not usually measured directly in terms of length, however, but rather as the product of the neutron density (number of neutrons per unit volume) and the mean velocity of the neutrons. Hence the units of neutron flux are (neutrons/cm^3) (cm/sec) = n/cm^{2}sec. Note that the neutron flux is *not* the rate at which neutrons flow through any planar unit of area.—EDITOR.

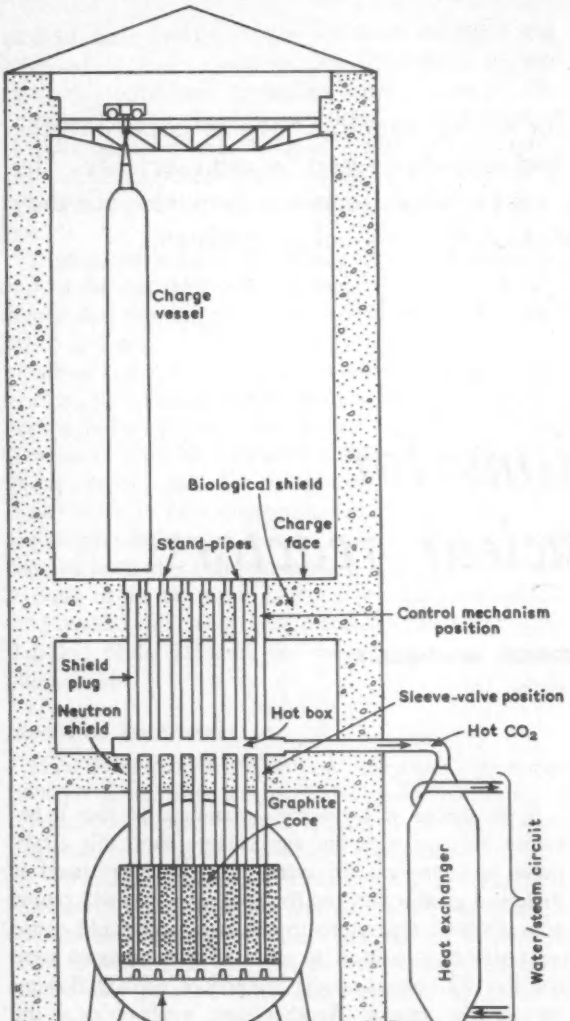


Fig. 1 Layout of nuclear reactor

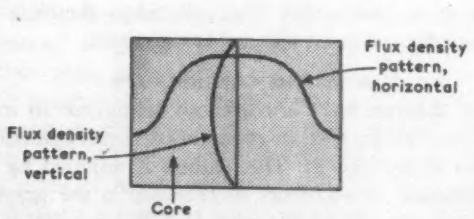


Fig. 2 Neutron flux distribution

placed at various predetermined positions which give the optimum neutron flux distribution. Some absorbers may consist of boron steel rods which are lowered or raised in the core according to whether the rate of fission has to be decreased or increased. These **fine control rods** are moved slowly but continuously, as necessary to trim the output. In addition there are many more so-called **coarse control rods,** which are raised to give the level of the power required.

It may be opportune to remind the reader at this point that to obtain an increasing fission chain reaction, k the multiplication factor must be greater than unity: but having reached the required power level it is necessary to maintain it by holding k at unity. If for some reason all the fine and coarse rods are fully in the core, or are not available for control, and k becomes greater than unity, then other means have to be employed to regain control. A further set of control rods is therefore fitted, but always withdrawn from the core and only dropped in an emergency to shut down the reactor: these rods are called **emergency control rods.**

Another control system called **secondary shut-down** (s.s.d.) is used in the unlikely event of the emergency rods failing to drop, and one method comprises magazines filled with boron steel balls which are held by a valve stop at the bottom. Each of these magazines is situated above a channel in the graphite core, placed at intervals over the lattice pattern of fuel channels. When the valves are opened, the balls fall freely into tubes in the channels, and there absorb reactivity to shut down the reactor. Unlike the long control rods, balls would not be restricted by the distortion of standpipes or channels if a severe rupture of the pressure vessel occurred.

OBTAINING INFORMATION

Flux scanning

Neutron flux may be monitored by suspending a wire (of a suitable material such as tungsten) in the core channels for say thirty minutes, then withdrawing it quickly and passing it through an ionization chamber to measure the activity induced on the wire. The varying signals are referred to their positions in the core; thus a record of the neutron flux distribution throughout the core is built up.

Gas sampling for burst slugs

Although not primarily part of the control, sampling of the flowing gas for radio-activity is very important, since an increase would indicate that a fuel slug had burst and must be replaced. This operation could affect power output to some degree, since it is abnormal and not in the 'burnt' fuel replacement schedule; the latter is carried out continuously and strictly in a predetermined rota, based on designed 'burn-up' rate.

Temperature

Thermocouples are built into the fuel slugs and they measure the temperature levels throughout the core.

WHAT THE CONTROLS DO

Control is effected by checking temperature and neutron flux, adjusting gas flow and operating control rods, and detecting burst fuel slugs and changing them.

A CLOSER LOOK AT CONTROL RODS

A control rod may be 2 in. in diameter and 20 ft long, and it could weigh 250 lb. If it dropped owing to a broken suspension cable, it could puncture the bottom of the pressure vessel—with disastrous results. To prevent this it is usual to introduce means for absorbing the kinetic energy of the falling rods, e.g. by building into the bottom of the rod a broach which would be driven into a hole in the rod if it hit the spring-mounted anvil under the core (Fig. 3).

Fig. 3 (left) Arrester for control rod

CONTROL ROD MECHANISMS

Winches which raise and lower the control rods are usually designed to fit into the reactor stand-pipes (Fig. 4). These pipes, which may be 6 in. in diameter, are welded to the pressure vessel, and terminate at the **charge face**† on top of the **biological shield*** over the pressure vessel. To facilitate the movement of vehicles such as **charge-machines** across the face, it is better to design the mechanisms so that they do not protrude.

It is necessary to prevent the quick withdrawal of any of the control rods from the core, since this might cause a dangerous increasing rate of activity to occur ($k > 1$).

Motors

A typical maximum speed of control-rod withdrawal is 0.2 in./min.

If electric motors, which operate from the a.c. mains, are used, the arrangement must be such that the speed cannot exceed the designed speed. Any potential source of failure must be removed from the design, and therefore brushes of any type are forbidden.

One type used is a reluctance motor (Fig. 5). This has a low-reluctance laminated-iron path in the rotor, and is controlled by special low-frequency supply (q.v.). Another type is the synchronous motor with a permanent-magnet rotor, controlled from a similar supply. One advantage of the latter over the former is that, in the event of an emergency drop, the speed of the falling rod can be gradually reduced by bringing into action the motor's natural regenerative braking. This is done by short-circuiting the stator windings with resistances operated by switches at predetermined positions reached by the rod whilst dropping into the core, whereas with the reluctance motor other braking arrangements have to be provided.

It will be realized that such arrangements cannot depend on any external electrical supply, since they may be required to work during a fault condition.

Emergency drops

When emergency control rods are required to drop into the reactor (so-called **scram** action) it is necessary that they fall into the core a distance such that effective control is obtained as quickly as possible. A typical case would be 8 ft in 1 sec. This means that the acceleration from rest would be 16 ft/sec² if constant. If the weight of the rod is 250 lb, then the force available to accelerate all the parts of the winch-driving mechan-

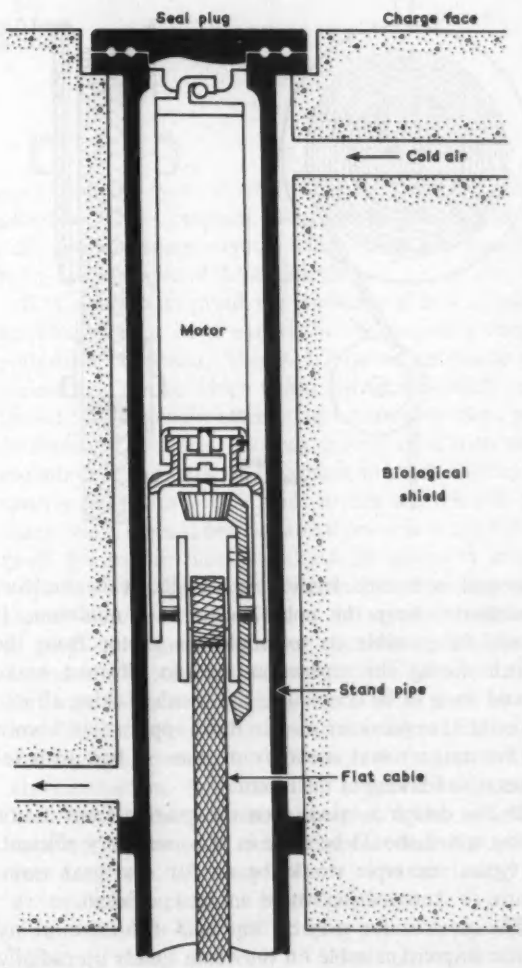
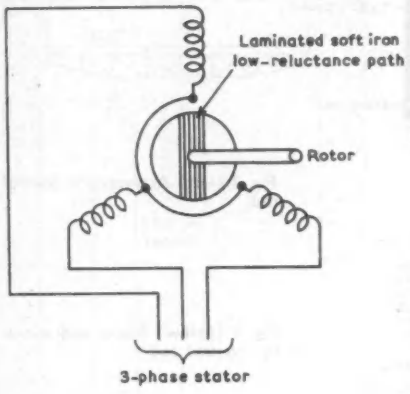
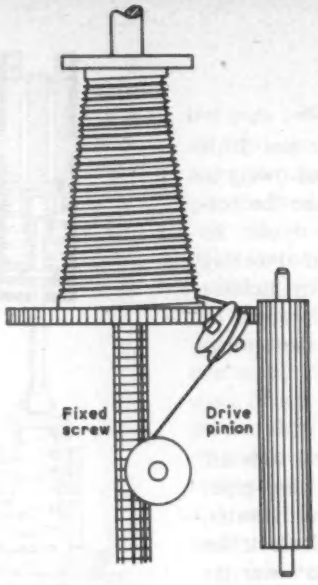


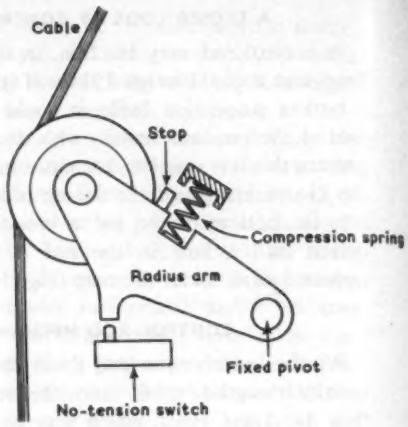
Fig. 4 (below) Motor and winch for control rod

† I.E. the floor through which the fuel slugs are passed ('charged') into and out of the core.—EDITOR.

* Shielding is required against dangerous emissions from the highly radioactive core. Concrete is a good shielding material, but it will crack if sufficiently heated by radiation. A ferrous shield is therefore customarily interposed between the reactor vessel and the surrounding concrete. This so-called *thermal shield* absorbs the neutrons and γ-rays that would overheat the concrete. The latter attenuates the remaining radiation to a level acceptable for safety of life—hence the name *biological shield* for this barrier.—EDITOR.







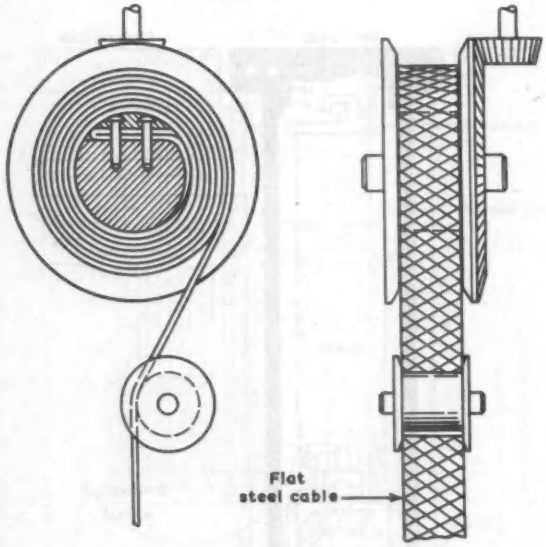


Fig. 5 (top left) Two-pole reluctance motor

Fig. 6 (below left) Concentric winding drum

Fig. 7 (top centre) Conic drum

Fig. 8 (above right) No-tension device

ism and overcome friction is 125 lb. It is therefore essential to keep the polar inertia to a minimum. It would be possible to uncouple the motor from the winch during this operation, but an effective brake would have to be coupled to the winch. Taking all into account, it appears (at least in those applications known to the author) that economy of mass is best with regenerative braking of the motor.

If this design is used, then the gearing from motor to the winch should be close in ratio and very efficient. A typical example would be an 8/1 spur-gear train. Worm or skew gearing would not be as efficient.

The quick action may be improved if the natural lay of the suspension cable on the drum builds up radially and not across the drum. The diameter of the coils is then at a maximum when the control rods are withdrawn (Fig. 6). At the commencement of drop the speed of rotation of the drum is the lowest referred to the cable speed. By this method the force required to accelerate the drum is small, but increases as the radius of the coils reduces on the drum. Thus a natural braking action is given later in the drop by increasing inertia forces, and the increasing regenerative braking forces of the motor with speed of cable pay-out.

Limitations of diametral space sometimes prevent the use of the simple type of drum. A drum arranged with its axis along the stand-pipe, instead of across it, has no such limitation. To obtain the same desirable features as the simple drum, the rope grooves are cut spirally on a conic surface of the drum (Fig. 7).

A lead-in pulley is necessary however, and to avoid the complication of a moving pulley, the drum is mounted on a fixed screw of pitch equal to that of the rope grooves. By taking off the cable tangentially coincident with the contact point of the spur-gear drive, frictional forces on the screw are reduced to negligible values.

Monitoring and limiting devices

It is necessary to transmit to the control desk information on the positions of the control rods in the reactor. A synchro transmitter is driven by gearing from the drum for this. A one-way-drive coupling is fitted at the winch motor to prevent continuous lowering of the rod from causing the cable on the drum to wind up the wrong way round. In addition, limit switches are arranged to give visible indication of the usual top and bottom limits of travel.

If a suspension cable breaks, an indicating switch is forcibly opened by a spring. The switch is normally held closed by the tension of the cable acting on a radius arm abutting on a limit stop and counterbalancing the spring. The operation of the radius arm should not depend entirely on the spring action, since a spring could break. It should be arranged to operate under its own weight, and the spring should be compressive rather than tensile (Fig. 8). *To be continued*

We are just beginning the true automation of process plant, but too many industries are still afraid of going beyond the standard three-term controller

Computers for process automation

by **P. F. SUTHERBY**
E.-A. Automation Systems Ltd

A WORKING DEFINITION OF AUTOMATION IS THAT IT IS the employment of any system that completely eliminates routine human effort. On this definition it is clear that partial automation has already been accomplished, to the extent that routine use of human senses in many industrial plants has been largely replaced by instrumentation. Now this process is being carried still further by automatic analysis instruments. Similarly, the routine use of human muscles is being rapidly replaced by power actuators and servo-devices. However, in all but the most simple cases, the link between the instrument and the actuation remains the human brain. In many cases the decisions are quite routine, but, except where the routine is simple enough to be handled by a two- or three-term controller, there are very few examples of these routine adjustments being handled by automatic means. One reason for this has been the unreliability of the more complex computing devices, but this has now been largely overcome by improved design and the use of such components as transistors. Yet there is still a reluctance in many industries to consider investing in any more complex control system than a standard three-term controller.

Overcoming ignorance

There are, of course, new problems to be faced in installing computers in industrial plant. The most important of these is often ignorance of the plant itself. Methods of obtaining the transfer function of a piece of chemical plant are generally long and complex, and their results are often difficult to interpret in terms of the various elements of the plant. The calculations used in plant design are usually relatively crude and approximate and often refer to the steady state. Furthermore, the experience of the operator is qualitative rather than exact, and his type of information is therefore rarely adequate for a computer program. In this article we shall consider some ways in which computers are now being used, in spite of these difficulties.

It is possible to avoid the problem of lack of plant knowledge, to a large extent, by the use of a simple optimizing controller. This is a form of automatic experimenting device which works between carefully controlled limits, always attempting to improve plant performance. The closest analogy is that of a man on a mountain in the dark; if he wishes to reach the top he can try always to walk uphill. In this way he will certainly reach *a* peak, but he cannot prove it is the *highest* peak. He can set about the task of ascent in several ways. For instance, he can try to find the line of steepest ascent; or, more simply, he can choose a direction such as north-south and walk along that line until he ceases ascending and starts to descend. He can then turn to an east-west line and walk along this until he stops ascending. If he continues the procedure, alternating north-south with east-west, he will reach the summit. There are numbers of variations and improvements on this basic procedure, but the principle of the optimizing approach is always to make experimental steps, act on the result of these experiments, and use very little accumulated or built-in plant knowledge.

A controller (Fig. 1) working on this principle is relatively cheap and easy to install. It requires (a) a method of calculating plant performance, in order that the result of a step may be assessed, and (b) the ability to alter two or three or even more of the plant inputs (for example, the set points of controllers, or the settings of valves or pumps). It is usual to put limits on the range of these alterations in order to ensure that the plant is not taken into a dangerous working condition.

This type of unit finds its greatest use in plants where the optimum conditions are continuously varying, so that no single set of experiments can find the best operating conditions. A specification can also be maintained at the same time, by the same optimizing unit, with very little increase in complexity.

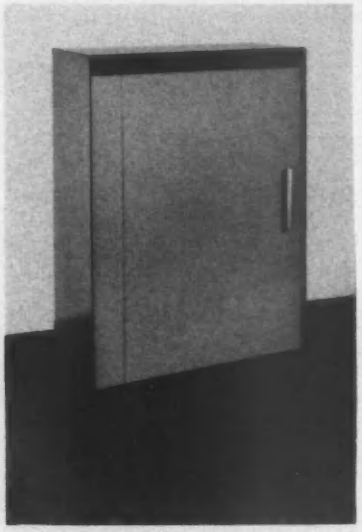


Fig. 1 The Elliott Optimat, an optimizing controller

Optimizers are really highly refined versions of a simple on-off regulator, but their most notable ability is to control in cases where the slope of an effect reverses. That is, if plant output is improved by increasing the setting of a valve up to a certain point, and above this point the output diminishes, then a conventional controller, continuous or on-off, will not be stable on both sides of the peak output. Optimizers, on the other hand, can either maintain a fixed point on one side or other of this peak, while optimizing some other function, or they can find the peak while maintaining some other specification.

There are limitations to this type of device, since it must allow the plant to settle after each change in input conditions before it can read the state of the output, and this time can make the overall optimization very slow. In cases such as this a more refined procedure may be required, possibly using a general-purpose computer requiring more plant knowledge, either built in or deduced by the computer as part of its normal optimizing function.

Learning from a simulator

In cases where it is necessary to find out more about plant response it is possible to use an analogue of the plant. A general-purpose analogue computer can be used (Fig. 2), or in certain cases it may be worth building a special simulator. This can be constructed from an initial study of the plant, and if necessary its performance can be adapted until it corresponds closely enough to the full-scale plant. The simulator can then be used to test various forms of control scheme, or the transfer functions of sections of the plant can be taken to be those of the corresponding section of the simulator.

The great advantage of this approach is that the simulator always bears a working resemblance to the plant; nearly every voltage represents a physical quantity which may be measured on the plant, while many potentiometer adjustments correspond directly to changing settings on the plant. Experiments can also be carried out on any convenient time scale. However, there are also many difficulties. Some arise from the complex mathematical expressions which govern, for instance, the flow of imperfect liquids or suspensions, and others come from the difficulty of dealing with partial differential equations. These difficulties also arise in any mathematical treatment of a plant, but in most simulations approximations are necessary to reduce the number of amplifiers used.

The problem of simulation on a large machine has been greatly eased by modern developments such as patch panel programming and (on very large machines) tape setting of coefficient potentiometers. Many studies, some of them of considerable scope, have been carried out on machines of this type, and although most of these studies have referred to existing plant, there has also been some examination of plant still in the design stage. It is only in the field of nuclear power-station design, however, that analogue-computer control studies have become an accepted part of the design procedure.

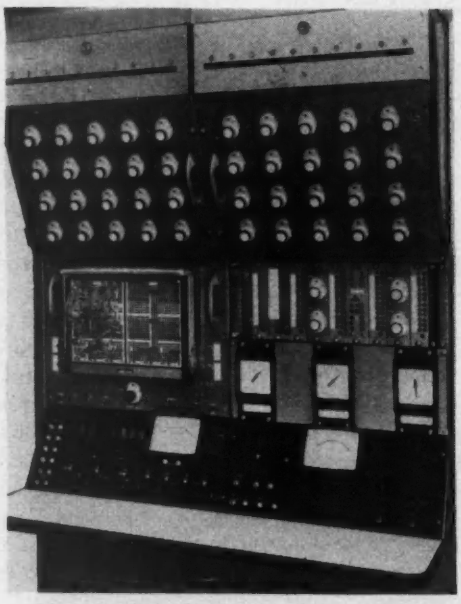


Fig. 2 The G.P.A.C. Mk. 11 analogue computer

Flexibility of digital computers

An alternative approach to control, where exact plant knowledge is limited, involves use of the great flexibility of a stored-program digital computer such as that shown in Fig. 3. If one of these machines is installed in a plant where knowledge is not immediately available for full computer control, it can initially be used to investi-

gate the plant. The program of its operations can then be adapted progressively to greater control of the plant as experience is gained.

This process of plant investigation can be carried on as part of a data-reduction system since, except at very high scanning rates, the computer will have a great deal

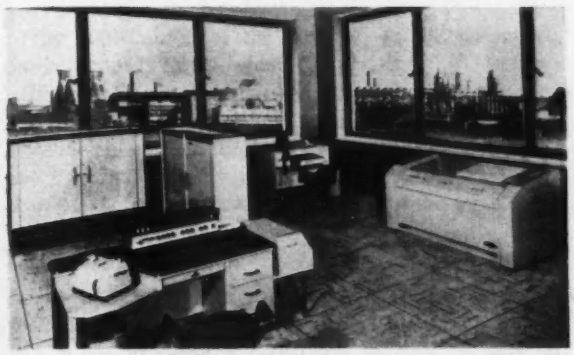


Fig. 3 A Panellit IS1609 installation

of time to spare for computation of useful information, performance analysis, and operating guides.

There is a parallel to this development program in the use of computers in the business field, where applications are usually commissioned progressively over a considerable period. This is a more rapid method of obtaining some of the advantages of computer control than by use of a performance recorder and analysis by an off-line computer. It would still be possible to arrange that a special-purpose computer replaced the general-purpose machine when the control routine was fully worked out, if this proved to be economical, and the general-purpose machine could then be used in another part of the plant. It is more likely that the use of the general-purpose machine could be expanded up to its full capacity in its original location.

The limitations imposed by lack of plant knowledge imply that many of the more striking uses of computers in control in the next few years will be in applications that are closer to data processing than to complete control of continuous plant, since the requirements of a data-processing scheme can in general be defined relatively easily.

Batch processes

There are many situations of this nature in batch processes, or where continuous processes are matched to batch processes, and in these a computer can be of great assistance in improving organization and data handling, and simple calculations can provide significant improvements. A typical example of this is an application in an English steel-works, where steel billets are cut from lengths of up to 450 ft into pieces between 30 ft and 18 in. long. Since this is done at three cutting points, there are many cases — particularly with the longer finished length—where considerable wastage can result. The computer is therefore arranged to measure the length of steel, as it is rolled, by means of a self-calibrating system. This length, the required length, and the tolerance of the final billet, are used to derive the optimum cutting lengths at the three shears, subject to the restrictions of plant layout. The calculation takes into account the probability of shearing inaccuracies in the equipment used. The cutting instructions are then transmitted to each operator in turn as the steel reaches him. Simple in application as it is, this use of a general-purpose computer is well justified, and the spare capacity of the machine can be developed at a later stage to perform other control functions.

Starting up complex plant

A further field for computer control is the starting-up of complex plant. The use of a stored program is a great advantage here, since one program can be used for starting up and progressively replaced in the store by the normal running program as starting up proceeds. These ideas for the use of general-purpose computers, and descriptions of some American applications, have been dealt with in more detail by Morley and Wood in two recent articles in *Control**.

Computer echelons

In general, the type of application so far considered for computer control requires a small- to medium-size computer (such as are now available) of perhaps 1000 to 4000 words immediate-access storage with, in some cases, a magnetic drum or film store to back this up. In more complex cases, where the amount of calculation and data is greater than can be handled by a single machine of this size, it is necessary to consider the choice between more small machines and a larger single machine. It is accepted that the computer, in general, should position the set points of conventional controllers rather than control actuators directly; not only does this relieve the computer of a great deal of repetitive checking, but it also means that the computer can be switched out and the plant will continue to run, since the signals from the computer are only used to modify settings. The use of several small computers in a complex scheme is an extension of this idea for the plant, and they can be linked to a central computer which collects information and issues instructions to the local computers to modify their procedure. On this principle of arranging computer echelons in the same way as levels of management, a computer control scheme can be developed in stages. An additional advantage of this approach is that failure of any single link in the chain does not bring the whole plant to a halt, but only lowers the efficiency of one section.

It is significant that more than 38 computers have now been sold in the United States for on-line application, and a market of sixty has been predicted for this year. The use of computers in direct connexion with process plant is only just starting, but it is the beginning of true automation, with all its tremendous implications of improved quality and output.

* 'Process control by computer' by R. A. Morley and M. B. Wood; May 1960, p. 144ff, and June 1960, p. 86ff.—EDITOR.

Controversy over this theory is spreading to western countries. Does it add anything to the armoury of the control engineer, or is it just a piece of mathematical embroidery?

The theory of invariance

by **L. FINKELSTEIN, M.SC., A.INST.P.**
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SOVIET WORKERS IN CONTROL ENGINEERING HAVE IN recent years shown considerable interest in the *Theory of invariance*, that is, the study of the conditions under which an output (or outputs) of a system is unaffected by one or more of the inputs. Work on the theory of invariance was started by G. B. Shchipanov (*1*), whose original paper was strongly criticized. The ideas were taken up and developed by others, among whom V. S. Kulebakin, N. N. Luzin, B. N. Petrov and A. G. Ivakhnenko deserve special mention. An extensive literature on invariance has been published; the proceedings of a conference on this subject, held in Kiev in October 1958 (*2*), contains many bibliographical references. Three papers were given at the recent first congress of I.F.A.C. in Moscow (*3*). A series of lectures based on invariance and allied topics was given in this country recently by Prof. A. G. Ivakhnenko, and was reported in *Control* (*4*).

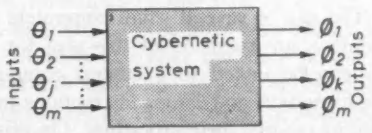

Fig. 1

The theory of invariance is concerned with some of the most fundamental problems of control engineering, but most of the literature is not easily accessible in the west. I therefore hope that this summary of some of the principal ideas of the theory, confined (for clarity) to linear systems with lumped parameters, will serve a useful purpose.

Equations of a linear cybernetic system

Consider a linear cybernetic system, i.e. a system which maintains definite relations among a number of physical variables, the relations between the variables being expressed by linear differential equations with constant coefficients. The independent variables of the system are termed the inputs and the dependent variables, outputs.

Let the inputs be denoted by $\theta_1, \theta_2, \theta_3, \ldots \theta_j, \ldots \theta_m$ and the outputs by $\phi_1, \phi_2, \phi_3, \ldots, \phi_k, \ldots \phi_m$ (Fig. 1). The behaviour of the system can then be represented by the following system of differential equations:

$$\left.\begin{array}{l} A_{11}\phi_1 + A_{12}\phi_2 \ldots + A_{1k}\phi_k \ldots + A_{1m}\phi_m = B_{11}\theta_1 + B_{12}\theta_2 \ldots + B_{1j}\theta_j \ldots + B_{1m}\theta_m \\ A_{21}\phi_1 + A_{22}\phi_2 \ldots + A_{2k}\phi_k \ldots + A_{2m}\phi_m = B_{21}\theta_1 + B_{22}\theta_2 \ldots + B_{2j}\theta_j \ldots + B_{2m}\theta_m \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ A_{m1}\phi_1 + A_{m2}\phi_2 \ldots + A_{mk}\phi_k \ldots + A_{mm}\phi_m = B_{m1}\theta_1 + B_{m2}\theta_2 \ldots + B_{mj}\theta_j \ldots + B_{mm}\theta_m \end{array}\right\} \quad (1)$$

where $A_{11} \ldots A_{mm}$ and $B_{11} \ldots B_{mm}$ are polynomials in the operator $D \equiv d/dt$, with constant coefficients. The operator polynomials A represent the dynamic properties of the system elements and the effects of signals derived from the outputs, i.e. feedback signals, while the polynomials B represent the effect of signals derived from the inputs, i.e. feedforward signals. There is no loss of generality in considering a system in which the number of inputs and outputs is equal. If the number of inputs is less than the number of outputs, it is possible to define the necessary additional inputs to be zero; while when the number of outputs is less than the number of inputs, the excess can be eliminated by combining those which directly aid or oppose each other. The set of equations is in practical cases linearly independent because of the uniqueness of the response of a linear system to a given set of inputs.

From the system differential equations 1 the outputs of the system can be expressed in the form

$$Q\phi_k = P_k \quad (2)$$

where

$$Q = \begin{vmatrix} A_{11} & A_{12} & \cdot & \cdot & A_{1m} \\ A_{21} & A_{22} & \cdot & \cdot & A_{2m} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ A_{m1} & A_{m2} & \cdot & \cdot & A_{mm} \end{vmatrix} \quad (3)$$

$$P_k = \begin{vmatrix} A_{11}A_{12}\ldots A_{1(k-1)} & (B_{11}\theta_1 + B_{12}\theta_2 \ldots + B_{1j}\theta_j \ldots + B_{1m}\theta_m) & A_{1(k+1)} \ldots A_{1m} \\ A_{21}A_{22}\ldots A_{2(k-1)} & (B_{21}\theta_1 + B_{22}\theta_2 \ldots + B_{2j}\theta_j \ldots + B_{2m}\theta_m) & A_{2(k+1)} \ldots A_{2m} \\ \ldots\ldots\ldots\ldots\ldots & \ldots\ldots\ldots\ldots\ldots\ldots\ldots & \ldots\ldots\ldots\ldots \\ \ldots\ldots\ldots\ldots\ldots & \ldots\ldots\ldots\ldots\ldots\ldots\ldots & \ldots\ldots\ldots\ldots \\ A_{m1}A_{m2}\ldots A_{m(k-1)} & (B_{m1}\theta_1 + B_{m2}\theta_2 \ldots + B_{mj}\theta_j \ldots + B_{mm}\theta_m) & A_{m(k+1)} \ldots A_{mm} \end{vmatrix} \quad (4)$$

Expanding the determinant P_k, equation 2 can be expressed in the form:

$$Q\phi_k = P_{k1}\theta_1 + P_{k2}\theta_2 \ldots + P_{kj}\theta_j \ldots + P_{km}\theta_m \quad (5)$$

where

$$P_{kj} = \begin{vmatrix} A_{11} & A_{12} & \ldots & A_{1(k-1)} & B_{1j} & A_{1(k+1)} & \ldots & A_{1m} \\ A_{21} & A_{22} & \ldots & A_{2(k-1)} & B_{2j} & A_{2(k+1)} & \ldots & A_{2m} \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ A_{m1} & A_{m2} & \ldots & A_{m(k-1)} & B_{mj} & A_{m(k+1)} & \ldots & A_{mm} \end{vmatrix} \quad (6)$$

The contribution of the input θ_j to the output ϕ_k can be denoted by ϕ_{kj} where $Q\phi_{kj} = P_{kj}\theta_j$ (7)

It should be noted that the determinant Q contains only terms describing the dynamic properties of the system elements and feedback loops, while the determinant P_{kj} contains only terms relating to outputs other than ϕ_k and to feedforward signals from the input θ_j.

Conditions of invariance

The purpose of a control system is either to render the controlled variable independent of input disturbances, or to cause a controlled variable to vary in exact agreement with an input. In the latter case the error should be independent of the command input and the controlled variable of all disturbance inputs. Thus the main purpose of a control system is the achievement of the conditions of invariance, i.e. the independence of some output or outputs of the system from one or more of the inputs. These conditions will now be considered for the general linear system described by equations 1.

The conditions of invariance of the output under consideration ϕ_k with respect to θ_j are that ϕ_{kj}, the contribution of θ_j to ϕ_k, should be zero. They are thus expressed by the equation of invariance

$$\phi_{kj} = (P_{kj}/Q)\theta_j = 0\,. \quad (8)$$

The above equation is of course satisfied if θ_j is equal to zero, but this is a trivial condition since it merely means that if the input is zero it does not contribute to the output.

The equation of invariance is also satisfied if

$$P_{kj} = 0 \quad (9)$$

If this condition is satisfied, initial conditions are zero, and θ_j is any analytic function, holomorphic at the origin of time, then ϕ_{kj} is identically equal to zero, throughout the interval of time over which θ_j is holomorphic. With such initial conditions, for any input function having the characteristics stated above, the output is completely unaffected by the input. With different initial conditions, or if the input is not a holomorphic function, steady-state invariance is achieved, but there will be a free transient output. Condition 9 is termed the condition of absolute invariance.

P_{kj} can be made to satisfy the condition of absolute invariance by suitable feedforward links from the input θ_j and suitable feedback links from outputs other than ϕ_k. Feedforward links from inputs other than θ_j, and feedback links from the output ϕ_k, do not affect the determinant P_{kj}, and hence cannot be used to achieve the condition of absolute invariance. It has further been shown that in order to satisfy this condition there must be in the system at least two paths between the input θ_j and the point of measurement of the output ϕ_k. The impossibility of achieving absolute invariance of a controlled variable by feedback from that variable is one of the fundamental facts of feedback control.

Another sufficient condition for the equation of invariance to be satisfied is $1/Q = 0$ (10)

Under this condition, as can be seen from equations 5 and 7, ϕ_k is absolutely invariant with respect to all inputs. The exact equality of $1/Q$ to zero cannot in general be realized in practical control systems, since it requires components with infinite parameters. Where this cannot be achieved $1/Q$ may be reduced to a small value, leading to a condition of approximate invariance. The adjustment of Q to attain invariance is, of course, carried out by selection of suitable system elements and feedback links.

If neither of the conditions 9 or 10 is satisfied, the equation of invariance 8 may still be satisfied for one or more specific forms of the input function. Thus for a specific input, say $\bar{\theta}_j$ we may have

$$\phi_{kj} = (P_{kj}/Q)\bar{\theta}_j = 0,\ P_{kj}/Q \neq 0 \quad (11)$$

For a specified function of time such as $\bar{\theta}_j$, it is in general possible to find a function of D, say $K(D)$, such that

$$K(D)\bar{\theta}_j = 0 \quad (12)$$

For example for $\bar{\theta}_j = \omega t$, $K(D) = D^2$

since $$D^2(\omega t) = 0 \quad (13)$$

In general $$K(D) = 1/\Theta_j(D) \quad (14)$$

where $\Theta_j(s)$ is the Laplace transform of $\bar{\theta}_j$.

Now if $K(D)$ is a factor of P_{kj}/Q, say

$$P_{kj}/Q = C(D)K(D) \quad (15)$$

then from equations 7, 12 and 15 we have

$$\phi_{kj} = (P_{kj}/Q)\bar{\theta}_j = C(D)K(D)\bar{\theta}_j = 0 \quad (16)$$

This form of invariance ensures independence of the output from certain forms of the input, no matter what the input magnitude is. Only the steady-state contribution of the input to the output is eliminated however, and there is a transient output. The condition of invariance 15 can be achieved by making $K(D)$ a factor of either P_{kj} or $1/Q$ (so long as $1/K(D)$ is not the factor of the other). In the former case, the required form of P_{kj} is achieved by feedforward links from the input θ_j, and feedback links from outputs other than ϕ_k, and the output is invariant with respect to the input θ_j only. In the case where $K(D)$ as a factor of $1/Q$ is achieved by adjustment of feedback links, invariance with respect to the specified form of all inputs is attained. The elimination of steady-state position error by integral control is a well-known example of invariance with respect to certain forms of input.

In addition to the conditions of invariance arising from the equation of invariance 18, it can be seen from equation 5 that ϕ_k will be invariant with respect to inputs θ_i and θ_j if $(P_{ki}/Q)\theta_i + (P_{kj}/Q)\theta_j = 0$ (17)

However, this equation is, in general, only satisfied

for certain inputs, specified in magnitude as well as form. For these inputs both steady-state and transient output invariance is attained.

Examples of invariance in simple systems

The Wheatstone bridge is a simple system which is often used in the literature to illustrate invariance. Consider the circuit shown in Fig. 2. The voltage $v(t)$ can be treated as an input with the currents as outputs. The equations of the network are

$$\begin{aligned}(R_1+R_3)i_1+R_2i_2+R_3i_3&=v(t)\\ R_2i_1+R_2i_2-R_3i_3&=0\\ (R_1+R_4+R_3)i_1-R_3i_2+R_3i_3&=0\end{aligned}\qquad(18)$$

This set of equations is a particular case of the general set of equations 1 (with two additional zero inputs defined).

Solving equations 18 for i_1, the current in BD,

$$i_1=\frac{\begin{vmatrix}1 & R_2 & R_3\\ 0 & R_2 & -R_3\\ 0 & -R_4 & R_3\end{vmatrix}}{\begin{vmatrix}(R_1+R_3) & R_2 & R_3\\ R_1 & R_2 & -R_3\\ (R_1+R_4+R_3) & -R_4 & R_3\end{vmatrix}}\cdot v(t)\qquad(19)$$

From this it can be seen that i_1 is the invariant with respect to $v(t)$ when the numerator of the fraction in equation 19 vanishes, that is when

$$R_2R_3-R_3R_4=0\qquad(20)$$

the balance condition of a Wheatstone bridge.

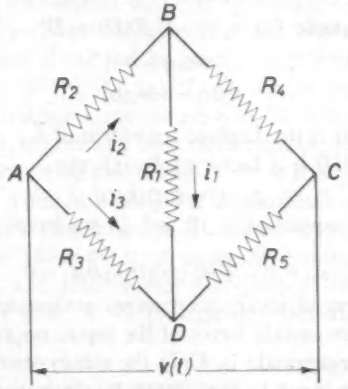

Fig. 2

Invariance of i_1 with respect to $v(t)$ can also be achieved by making the denominator of the fraction in equation 19 infinite. This can be done by making R_1 infinite. This simply means that if the diagonal arm is open-circuited, the current in it will be zero and independent of the bridge voltage. By making R_1 large, approximate invariance is obtained.

If a capacitor were placed in the diagonal arm BD, it would mean that the steady-state current in the arm would be independent of step changes of bridge voltage (though not of course of harmonic changes).

Another example of a simple system is the control system shown in Fig. 3. The controlled quantity is the output of a simple element characterized by a gain K and a single time constant τ. The control is accomplished by a single feedback link and a feedforward link, described by differential-operator terms A and B respectively. If the input to the system is denoted by θ

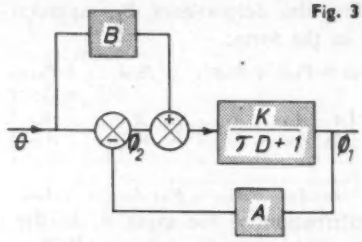

Fig. 3

and the controlled variable and the error are denoted by ϕ_1 and ϕ_2, and defined as the outputs of the system,

$$(1/K)(\tau D+1)\phi_1-\phi_2=B\theta,\quad A\phi_1+\phi_2=\theta\qquad(21)$$

These equations are again a particular case of the general equations 1.

Solving equations 21 we obtain an expression for the error:

$$\phi_2=\frac{\begin{vmatrix}(1/K)(\tau D+1) & B\\ A & 1\end{vmatrix}}{\begin{vmatrix}(1/K)(\tau D+1) & -1\\ A & 1\end{vmatrix}}\cdot\theta\qquad(22)$$

Absolute invariance of ϕ_2 with respect to θ is attained when

$$AB=(1/K)(\tau D+1)\qquad(23)$$

It can be seen that the feedforward link or its equivalent is essential to achieve absolute invariance, as there must be at least two paths between the input and the point of measurement of ϕ_2.

It can be seen from equation 22 that without the feedforward link approximate invariance can be attained by having a large gain in the feedback loop.

Conclusions

Before drawing any conclusions about the theory of invariance it is necessary to emphasize that this short survey cannot do full justice to the breadth and rigour of the investigations carried out in this field, mainly it appears in the Soviet Union.

The study of invariance is of some interest. It has produced a very satisfactory and general theoretical treatment of some fundamental problems of control.

Some of the conclusions have been merely mathematical formulations of well-known facts. The theory of invariance has however given impetus to much rigorous study of the theory of control systems. Most important of all, it has drawn renewed attention to the advantages of the more general use of feedforward in combination with feedback, and has directed the consideration of engineers to greater use of this form of control.

Further work on invariance and allied topics lies in such fields as the application of this theory in system design, and the achievement of invariance in practical control systems by combining feedforward with feedback. There is also a need, in this as in many other fields of control engineering, for a comprehensive and critical review of Soviet work.

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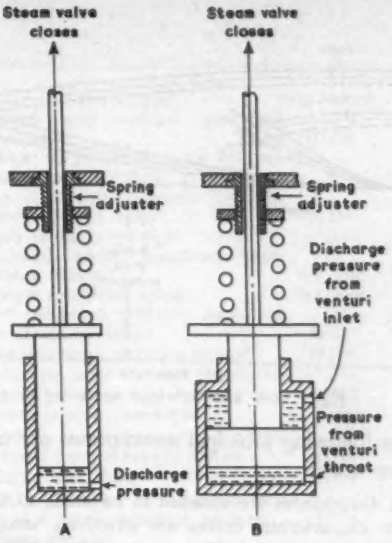
PART 1

Traditional design procedures, without stability or response calculations, can lead to chaos during the commissioning of plant and poor performance later



Boiler feed discharge systems under changing load

by **A. J. MORTON, M.SC., A.M.I.MECH.E.**
Central Electricity Generating Board

THE TRADITIONAL PROCEDURE OF DESIGNING CONTROL systems for steam power plant largely by inspired guesswork, without any stability or response calculations, is becoming inadequate for modern plant. Chaos can occur during the commissioning of equipment designed in this way, jeopardizing the machinery and causing expensive delays. Even when successfully commissioned, the equipment may give a performance which is far from the optimum, restricting freedom of operation and leading to general distrust and cynicism.

A particularly pressing problem is the control of water level in highly rated boilers, and this article represents a first attempt to analyse the behaviour of a feed discharge system, including pump, driving turbine, governor and downstream pipework. A complete study of the problem would cover the equally important subjects of conditions inside the boiler and the characteristics of the feed regulator control system, but the present limited investigation brings to light some facts which, besides being useful in themselves, may serve to encourage further efforts along the same lines. Some evidence from actual trials, which will be briefly mentioned, gives encouraging confirmation of the analysis.

The complete water-level control loop includes the pump, governor, discharge system, regulating valve and its control system, and the boiler itself, and this must be considered as a whole in any really adequate theory of stability. Consideration of the individual sub-assemblies is an essential preliminary to the development of such a theory, and this article is therefore intended as a limited but necessary contribution to a much larger whole.

The mathematical technique here employed does not enable us to predict the character of large oscillations, or the response to large disturbances, but it does permit this to be done for small disturbances, and hence makes possible a prediction as to whether or not such disturbances will die away or increase indefinitely. This is the criterion of stability, which is therefore determinate from the present theory for the components considered.

FUNDAMENTAL RELATIONS

Basic assumptions

The usefulness of the theory culminating in equations 15, 17, 20 and 23 depends on the validity of the assumptions on which it is based. In making these assumptions, the object has been to represent reasonably the known or probable characteristics of the engineering components without unmanageable mathematics.

The principal difficulty in constructing any theory of this sort is to decide which factors may be neglected with safety. This is an engineering problem which calls for much more than a mere theoretical understanding of the physical laws involved; it requires in addition a very close acquaintance with the actual operational behaviour of complete steam plants and all their components. It is therefore very easy to construct a theory which, though perfectly correct mathematically, is practically worthless because of an incorrect assumption or a neglected factor, and all analytical results, including the present ones, must be treated with reserve until confirmed experimentally.

This paper is based largely upon work carried out at Pametrada Research Station, Wallsend, Northumberland, and is published by kind permission of the Council and Director of Pametrada. Responsibility for all expressions of opinion and for the accuracy of calculations rests entirely with the author.

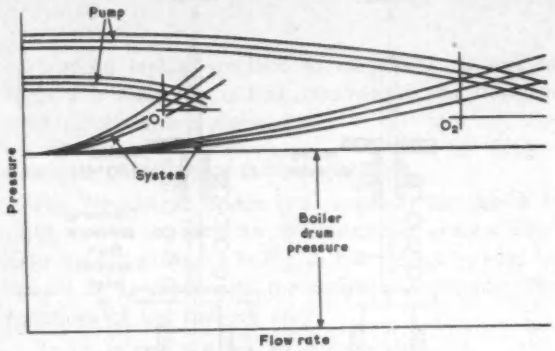


Fig. 1 Low- and high-load operating zones

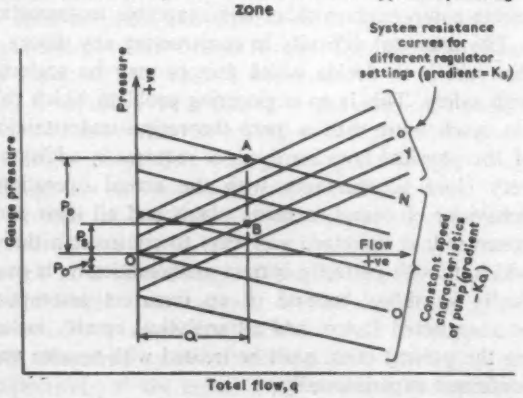
The following principal assumptions are made in the present work:

1. All disturbances are assumed to be small, so that the relevant characteristic curves are effectively straight lines in the zone concerned. Numerical results which depend on the slopes of characteristics will therefore apply only in the region of one particular load. This excludes non-linear equations and simplifies the mathematics.
2. The pressure drop in a given system is assumed to be proportional to the square of the flow.
3. Elasticity of the water and piping is neglected. This means that the theory applies only to oscillations whose periodic time is much greater than the time required for a pressure wave to travel through the discharge system.
4. The boiler drum pressure is assumed constant. In actual fact, the drum pressure is affected by feeding rate, and the present theory therefore requires modification if applied to events slow enough for appreciable changes in drum pressure to occur from this cause. This appears unlikely except for oscillations having a period of many seconds, but such oscillations may be important in considering the behaviour of the complete water-level control loop.
5. Mechanical friction and backlash in the governor of the feed-pump driving-turbine are ignored.
6. Pump and turbine characteristics are as detailed later.

Discharge system

The general form of the pump and system characteristics is shown in Fig. 1, in which the constant-speed curves for the pump are shown intersecting the various system resistance lines, each of which corresponds to a given setting of the feed regulator. A large increase in load will involve a shift of the operating zone from the area near O_1 to that near O_2, and owing to the change in slope and spacing of the characteristics this shift cannot be represented by linear equations. For small changes in the vicinity of O_1 or O_2, however, the characteristics may be regarded as straight lines, and a small portion of the complete diagram is shown in Fig. 2, in which the point O represents any convenient origin which is somewhere near the operating zone and from which pressure and flow can be measured.

Fig. 2 Pump and system characteristics in typical operating zone



The system resistance depends on the feed regulator opening, and any small change in the lift y of this valve will cause the relevant portion of the system resistance line to be shifted parallel to itself, thus altering the value of P_0, which is the system resistance at zero flow when both pressure and flow are measured from the arbitrary datum adopted above. By defining the regulating valve lift y as zero when it is such as to make P_0 zero, and considering small changes only, we may write

$$P_0 = -K_F Y \tag{1}$$

At any flow Q, the system resistance P_S, still measured from the same datum, is

$$P_S = P_0 + K_S Q \tag{2}$$

or

$$P_S = K_S Q - K_F y \tag{3}$$

If P_D is the pump discharge pressure, measured from the same datum as P_S, the force available for increasing the velocity Q/A of the mass $Al\rho$ of water in a discharge pipe of length l and uniform cross-sectional area A is

$$A(P_D - P_S) = Al\rho . D\frac{Q}{A}$$

using the operator D to denote differentiation with respect to time. Hence

$$P_D - P_S = \frac{l\rho}{A} DQ \tag{4}$$

If the discharge system consists of several lengths l_1, l_2 ... of respective cross-sectional areas, A_1, A_2 ..., the term lp/A must be replaced by

$$\rho\left(\frac{l_1}{A_1} + \frac{l_2}{A_2} + \ldots\right)$$

Centrifugal pump

Pump and turbine

The discharge pressure is a function of rotational speed and flow, small changes in these quantities being linearly related by the expression

$$P_D = K_P N - K_Q Q \tag{5}$$

in which K_P and K_Q are positive constants for most feed pumps. This is illustrated in Fig. 2.

The resisting torque T_R experienced by a centrifugal pump rotor increases partly with speed N and partly with flow Q. For small changes, therefore,

$$T_R = K_T N + K_R Q \tag{6}$$

This implies that torque is defined as zero when the pump operating point B coincides with the arbitrary origin O in Fig. 2.

In the case of a turbo-driven pump, the driving torque exerted by the turbine increases with the governor valve lift x but diminishes with speed N when the valve lift remains unchanged. Hence

$$T_D = T_0 + K_G x - K_D N \tag{7}$$

NOMENCLATURE

SYMBOL	DEFINITION	DIMENSIONS
A	Cross-sectional area of discharge pipe	ft²
C	Equilibrium value of feed flow when regulating valve is set to opening defined as zero	ft³/s
C_1	Increase in equilibrium value of feed flow per unit increase in regulating valve opening	ft²/s
D	Operator denoting differentiation with respect to time	—
e	Exponential function	—
$F(D)$, $f(D)$	Polynomial functions of D	—
I	Moment of inertia of rotating parts of pump and driving turbine	lb ft s²
j	$\sqrt{(-1)}$	—
K_D	Decrease in turbine driving torque unit increase in speed at constant governor valve lift	lb ft s
K_F	Decrease in system resistance per unit increase in feed regulating valve lift at constant flow	lb/ft⁸
K_G	Increase in turbine driving torque per unit increase in governor valve lift at constant speed	lb
K_P	Increase in pump discharge pressure per unit increase in speed at constant flow	lb s/ft²
K_Q	Decrease in pump discharge pressure per unit increase in flow at constant speed	lb s/ft⁵
K_R	Increase in pump resisting torque per unit increase in flow at constant speed	lb s/ft²
K_S	Increase in system resistance per unit increase in flow at constant regulator setting	lb s/ft⁵
K_T	Increase in pump resisting torque per unit increase in speed at constant flow	lb ft s
K_V	Decrease in governor valve lift per unit increase in speed (speed governed pumps only)	ft s
K_W	Decrease in governor valve lift per unit increase in pump discharge pressure at constant flow (pressure governed and venturi governed pumps only)	ft³/lb
K_Y	Increase in governor valve lift per unit increase in flow at constant pump discharge pressure (venturi governed pumps only)	s/ft²
l	Length of discharge pipe	ft
N	Rotational speed measured from arbitrary datum	rev/min
n	Absolute rotational speed	rev/min
P_D	Pump discharge pressure measured from arbitrary datum	lb/ft²
p_D	Pump discharge pressure (gauge)	lb/ft²
P_S	System resistance measure from arbitrary datum	lb/ft²
p_S	Absolute system resistance	lb/ft²
Q	Feed flow through pump and system measured from arbitrary datum	ft³/s
q	Absolute feed flow	ft³/s
q'	Equilibrium value of absolute feed flow at a given regulator opening	ft³/s
s	Laplace operator	—
T_1, T_2, T_3	Exponential delays in response of flow rate to regulator adjustment	s
T_D	Turbine driving torque measured arbitrary datum	lb ft
T_R	Pump resisting torque measured from arbitrary datum	lb ft
t_R	Absolute pump resisting torque at speed n	lb ft
t_{RO}	Absolute pump resisting torque at speed n and zero absolute flow	lb ft
x	Lift of turbine governor valve measured from arbitrary zero	ft
y	Lift of feed regulating valve measured from arbitrary zero	ft
ρ	Density of water handled by feed pump	lb s²/ft⁴
ϕ	Phase lag between feed regulator movement and feed flow rate	—
ω	Angular velocity of rotating vector corresponding to an oscillation of frequency $\omega/2\pi$	s⁻¹

The constant T_O is required because, for consistency, T_D must be measured from the same datum as T_R, as defined above.

The difference between the driving and resisting torques determines the angular acceleration of the pump rotor according to the law

$$T_D - T_R = \pi IDN/30 \qquad (8)$$

Governor

An ideal constant-speed pump which never departed from its equilibrium speed, despite variations in load, would be represented by the further equation

$$N = 0 \qquad (9)$$

For a normal speed governor in which valve lift diminishes as speed increases,

$$x = -K_V N \qquad (10)$$

so that x is zero whenever the pump is operating on the constant-speed line $N = 0$ (see Fig. 2).

For a simple pressure governor in which valve lift diminishes as discharge pressure increases (see Fig. A in heading illustration)

$$x = -K_W P_D \qquad (11)$$

In this case x is zero whenever the discharge pressure falls to the arbitrary datum shown in Fig. 2.

A type of governor has been developed in recent years which is similar to a pressure governor, but incorporates a device for increasing the discharge pressure as the flow increases. This compensates approximately for the increased pressure-drop in the discharge system and allows a more constant pressure-drop to be maintained across the feed regulating valve at all loads. Fig. B in our heading illustration is a sketch of such a governor, the upper cylinder being open to pump discharge pressure and the lower connected to the throat of a venturi in the pump discharge pipe. At high rates of flow, the greater pressure-difference between the inlet and throat of the venturi assists the governor spring to open the steam valve further than would be the case with the simple pressure governor, shown as Fig. A in the heading illustration.

For a venturi governor of this type, the equation for the lift of the governor steam valve is

$$x = -K_W P_D + K_Y Q \qquad (12)$$

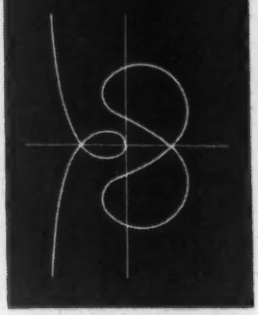
where P_D and Q are measured from the datum levels shown in Fig. 2.

Equations 10–12 are of course valid only for governors which respond at once to changed conditions. If the response is sluggish, a time constant is introduced which no one is ever likely to know with any accuracy. It is assumed throughout the following work that the governor is not sluggish.

To be continued

NO. 1 OF A NEW SERIES

These are the basic ideas to grasp before going on to complex frequency analysis and root locus methods



Pole-zero approach to system analysis

by **P. F. BLACKMAN**
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IN ANALYSIS AND DESIGN OF CONTROL SYSTEMS A dominant part is played by the concept of frequency response, either for individual portions of a system or for an entire system. A knowledge of frequency response characteristics for various types of components and situations is part of the normal analytic equipment of every control engineer.

Although the basic form in which the characteristics of a unit may be represented is a differential equation, this form is tedious and unwieldy for use to investigate two of the standard types of problem that arise. First, to predict the performance of several units when connected together; and second, how this performance may be modified when loops are closed in the system. To make such problems manageable it is normally assumed that adequate information can be obtained if all variations in the system are considered to be sinusoidal, then the differential equations can be converted into frequency response expressions. These expressions, which allow system performance to be investigated by appropriate multiplication, addition and related techniques, so often form the starting point of analysis that it is easy to forget that they originate from differential equations.

Analysis and design can be carried out entirely in terms of frequency responses, but the designer is often ultimately concerned with the transient response of a system. Direct links between frequency response and the corresponding transient response are somewhat tenuous, and in practice the frequency response characteristic is adjusted using various design criteria which will normally result in a satisfactory transient response.

The idea of sinusoidal oscillations for general analysis has been extended to the use of oscillations varying in amplitude exponentially with time, so-called *complex frequencies*, and these have been applied as the *root locus* method developed by Evans (*1*) for closed-loop system investigation. These methods, which describe units and systems by a pattern of points (*poles* and *zeros*) in a plane, have certain attractive features when compared with normal frequency response techniques.

With these methods the pole-zero pattern of a unit or system is the basic item of information which forms the starting point of analysis, and from this pattern spring both the normal frequency response and the corresponding transient response. This permits a more direct link to be established between frequency response and transient response, both of these being manifestations of the basic pole-zero pattern. In addition much of the analysis can be interpreted graphically, which is a very valuable feature enabling one to obtain qualitative information relatively easily in complicated or unusual situations which are not so readily amenable to normal frequency response analysis. As well as having these qualitative advantages, the methods can also yield detailed numerical results, and are more easily

adapted to the problem of obtaining expressions for the transient response of systems.

These methods have much more extensive applications than purely to control systems, being generally applicable to any situation governed by linear differential equations. This considerably widens their scope.

Frequency response of a simple system

In order to develop complex frequency analysis ideas, it is useful to review initially some features of linear constant-coefficient differential equations which are particularly relevant to this method of analysis. A convenient starting point is to consider the simple spring-mass system of Fig. 1.

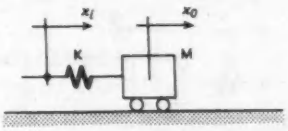

Fig. 1 Simple spring-mass system

Suppose that it is required to investigate the motion of the mass (the *output*) for some motion of the free end of the spring (the *input*). The mass M is free to move horizontally without friction, and the two co-ordinates x_i, x_o, represent displacements of input and output respectively. Consideration of the force balance of the system enables one to write the following equation:

$$K(x_i - x_o) = M\frac{d^2x_o}{dt^2}$$

or

$$\frac{M}{K}\frac{d^2x_o}{dt^2} + x_o = x_i$$

where K is the spring rate in force per unit change of length. This equation is quite general in that it relates

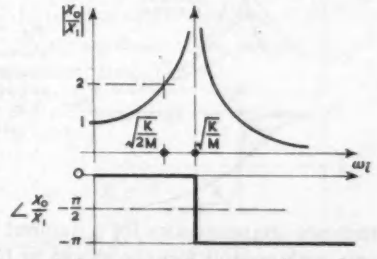

Fig. 2 Frequency response of spring-mass-system

to instantaneous force balance and does not depend on any particular form of assumed input motion.

Since the choice of input motion is arbitrary it is convenient to choose a sinusoidal displacement oscillation

$$x_i = X_i\sin\omega_i t$$

where X_i gives the magnitude of the input displacement. The solution of the equation x_o, may be found by guessing a possible solution and investigating whether the solution satisfies the equation. An initial guess might be

$$x_o = X_o\sin\omega_i t$$

in which an output of the same frequency is anticipated since the system is linear, and this may be substituted to yield

$$-\frac{M}{K}X_o\omega_i^2\sin\omega_i t + X_o\sin\omega_i t = X_i\sin\omega_i t$$

so that $\sin\omega_i t$ can be cancelled throughout, giving as a final relation

$$\frac{X_o}{X_i} = \frac{1}{1 - \omega_i^2 M/K}$$

This expression gives the relative input and output motion as a function of M, K, ω_i, and is shown in general magnitude and phase form in Fig. 2, to give the usual *frequency response* or *resonance* curve, indicating that $\left|{}^{X_o}/_{X_i}\right|$ is finite for all frequencies other than

$$\omega_i = \sqrt{{}^{K}/_{M}}$$

where the output motion theoretically becomes infinite for a finite input motion. Below and above this frequency the output and input motions are in phase and out of phase respectively.

The situation considered so far represents the *steady state* solution of the equation in the sense that the output is purely the response due to a continuously maintained input. For example, if the input frequency is chosen as

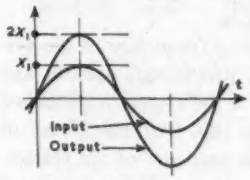

Fig. 3 Spring-mass system response for $\omega_i = \sqrt{(K/2M)}$

$$\omega_i = \sqrt{{}^{K}/_{2M}}$$

substitution into the expression for relative input and output motion gives

$$X_i/X_o = 1/(1 - \tfrac{1}{2}) = 2$$

implying that for an input

$$x_i = X_i\sin\sqrt{{}^{K}/_{2M}}\cdot t$$

the output is

$$x_o = 2X_i\sin\sqrt{{}^{K}/_{2M}}\cdot t$$

with twice the magnitude, but in phase as in Fig. 3.

System natural frequency

Although the response of the spring-mass system has been considered in the presence of a continuous input at a particular frequency ω_i, in which case the output is also at the frequency ω_i, it is also possible for the system to maintain self-oscillations in the absence of any continuous input. If, for example, the free end of the spring is fixed and the mass pulled away from the equilibrium position and released as in Fig. 4, the equation governing the motion becomes

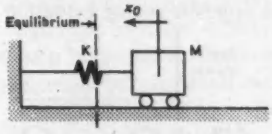

Fig. 4 System displaced from equilibrium

$$M\frac{d^2x_o}{dt^2} + Kx_o = 0$$

and again sinusoidal motion might be anticipated, though the frequency is so far undetermined. If the out-

put motion is anticipated as

$$x_o = X_o \sin\omega t$$

this may be substituted to yield

$$-M\omega^2 X_o \sin\omega t + KX_o \sin\omega t = 0$$

and $X_o \sin\omega t$ cancels throughout, so that the only information obtained is

$$\omega = \sqrt{K/M} = \omega_n$$

which defines a frequency, the *natural frequency* of the system ω_n, in terms of the parameters of the system. It should be noticed that the amplitude value X_o cancels so that no information is directly available concerning the amplitude of oscillation. If the solution had been postulated as

$$x_o = X_o \cos\omega t$$

and substituted, $X_o \cos\omega t$ would cancel, so that again the only information available would be

$$\omega_n = \sqrt{K/M}$$

These results define the natural frequency of the system purely as a frequency of oscillation, without any specification of the magnitude. If the system is disturbed in any way it will oscillate at this frequency, and of particular interest is the *impulse response* of the system.

Impulse response

The impulse response is the response of the system after being subjected to a very large disturbance of very short duration, in other words after a sudden transfer of energy into the system. A very large force might be applied to the mass for a very short time to give the mass a finite velocity in the short time interval, but with substantially no displacement during the interval.

Applying this to the present system, together with some physical reasoning, we find that the impulse displacement response will be a sine wave, since there will be an initial velocity but zero displacement immediately after the impulse. As the mass moves from the initial position the spring is stretched, finally bringing the mass to rest at maximum spring extension. The initial kinetic energy of the mass has been converted into strain energy in the spring, and the spring will move the mass back towards the initial position, the mass subsequently coming to rest with an equal and opposite spring extension.

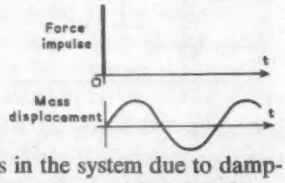

Fig. 5 Impulse-displacement response of spring-mass system

Since there is no energy loss in the system due to damping, the oscillation would be maintained indefinitely, as in Fig. 5.

System with damping

If a dashpot is added to the system as in Fig. 6, the equation relating input and output motions becomes

$$\frac{M}{K}\frac{d^2x_o}{dt^2} + \frac{C}{K}\frac{dx_o}{dt} + x_o = x_i$$

where C is the viscous constant for the dashpot in force per unit velocity. If again the input displacement is assumed to be sinusoidal

$$x_i = X_i \sin\omega_i t$$

the response may be anticipated as

$$x_o = X_o \sin\omega_i t$$

Substitution of the result now yields

$$-\frac{M}{K}X_o\omega_i^2 \sin\omega_i t + \frac{C}{K}X_o\omega_i \cos\omega_i t + X_o \sin\omega_i t = X_i \sin\omega_i t$$

and owing to the single differentiation associated with the damping term, the factor $\sin\omega_i t$ no longer cancels throughout as in the previous example, so that this simple choice for the output is no longer valid.

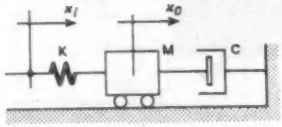

Fig. 6 Spring-mass-dashpot system

As a next choice a phase change between input and output might be anticipated with a solution of the form

$$x_o = X_o \sin(\omega_i t + \phi)$$

which may be substituted into the equation, and after considerable trigonometrical manipulation the following may be obtained

$$\left|\frac{X_o}{X_i}\right| = 1/\sqrt{(1 - \omega_i^2 M/K)^2 + (\omega_i C/K)^2}$$

$$\phi = \tan^{-1}[-(\omega_i C/K)/(1 - \omega_i^2 M/K)]$$

giving the response in magnitude and phase form. For varying frequency of input and damping these expressions may be plotted to yield the usual frequency

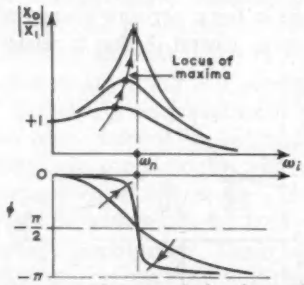

Fig. 7 Effect of varying damping on frequency response characteristics of spring-mass-dashpot system. Arrows indicate decreasing damping

response characteristics for a damped second-order system, with general form as shown in Fig. 7.

For the response characteristics obtained, two general points may be noted:

- **a** The actual manipulation involved in making the substitution and finally obtaining expressions for $|X_o/X_i|$ and ϕ is quite considerable.
- **b** To obtain the final graphical form it is necessary to plot a fairly complicated expression, and the salient qualitative features, such as rapid phase-change for $\omega_i \simeq \omega_n$ if the damping is small, or the form of the locus for maximum response with damping variation, are not particularly evident until the results are plotted.

Exponential form of solution

The first point mentioned above shows that some of the difficulties arise through the choice of a solution in the form of sine (or cosine) and phase angle, and apart from the rather special case of an undamped system these are not particularly convenient forms of solution.

As an alternative an exponential form of input and solution

$$e^{j\omega_i t} = \cos\omega_i t + j\sin\omega_i t$$

is much more convenient, essentially since repeated differentiation to any order yields

$$\frac{d^n}{dt^n}(e^{j\omega t}) = (j\omega)^n e^{j\omega t}$$

so that the exponential term can always be cancelled throughout, and in addition normal complex-number manipulation enables one to obtain final results much more easily.

Considering the mass-spring-dashpot system of Fig. 6, the governing equation is

$$\frac{M}{K}\cdot\frac{d^2x_o}{dt^2} + \frac{C}{K}\cdot\frac{dx_o}{dt} + x_o = x_i$$

and if input and output are specified as

$$x_i = X_i e^{j\omega_i t};\ x_o = X_o e^{j\omega_i t}$$

where X_o may be complex, containing both magnitude and phase information, these may be substituted into the equation yielding

$$-\frac{M}{K}\omega_i^2 X_o e^{j\omega_i t} + \frac{C}{K}j\omega_i X_o e^{j\omega_i t} + X_o e^{j\omega_i t} = X_i e^{j\omega_i t}$$

and cancelling $e^{j\omega_i t}$ gives

$$X_o/X_i = 1/((1 - \omega_i^2\,{}^{M}/_{K}) + j\omega_i\,{}^{C}/_{K})$$

which may be written immediately in magnitude and phase form as

$$\left|{}^{X_o}/_{X_i}\right| = 1/((1 - \omega_i^2\,{}^{M}/_{K})^2 + (\omega_i\,{}^{C}/_{K})^2)^{\frac{1}{2}};$$

$$\angle({}^{X_o}/_{X_i}) = \tan^{-1} - (\omega_i C/K)/(1 - \omega_i^2 M/K)$$

These are the results obtained previously but with far less manipulation than if the input and output were specified as

$$x_i = X_i\sin\omega_i t;\ x_o = X_o\sin(\omega_i t + \phi)$$

The exponential form of solution may be applied to the equation for the spring-mass when subject to no continuous external disturbance, Fig. 4,

$$\frac{M}{K}\frac{d^2x_o}{dt^2} + x_o = 0$$

and by assuming

$$x_o = X_o e^{j\omega t}$$

substitution yields

$$-\omega^2 M/K + 1 = 0$$

or

$$\omega = \sqrt{{}^{K}/_{M}} = \omega_n$$

again defining the same natural frequency as before.

To determine the natural frequency of the same system, but with damping added as in Fig. 6, and with the free end of the spring clamped, the equation becomes

$$\frac{M}{K}\frac{d^2x_o}{dt^2} + \frac{C}{K}\frac{dx_o}{dt} + x_o = 0$$

and again anticipating

$$x_o = X_o e^{j\omega t}$$

Substitution leads to

$$-\omega^2 X_o M/K + j\omega X_o C/K + X_o = 0$$

or

$$1 - \omega^2 M/K + j\omega C/K = 0$$

which does not directly define a possible value for ω_n, indicating that $e^{j\omega t}$ is not the correct form of solution for the natural frequency of a system with damping.

Complex frequencies

The exponential form of solution $e^{j\omega t}$ used previously, which represents an oscillation of constant magnitude, could be extended to a more general form of oscillation of the form

$$e^{(\alpha+j\omega)t} = e^{pt}$$

representing oscillations varying exponentially in magnitude with time, such oscillations often being termed *complex frequencies*.

Since the frequency variable p is complex it is useful to consider this variable in a plane, the *p-plane* or *complex frequency* plane, and every point in the plane

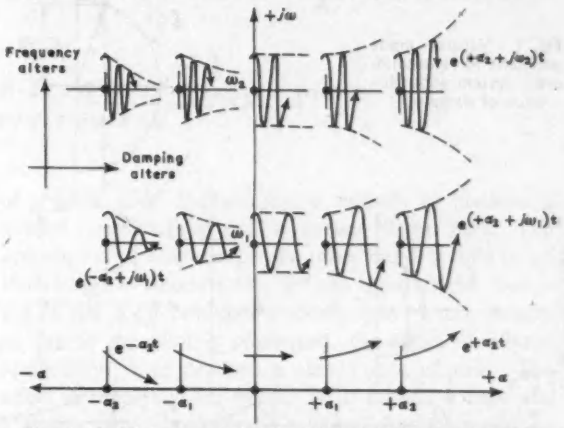

Fig. 8 Oscillations associated with points in the complex frequency plane. Not to scale, this diagram is expanded along the α axis for clarity

defines a particular form of oscillation. Values of p along the imaginary axis correspond to constant-magnitude oscillations, values along the real axis correspond to non-oscillatory exponential forms, and general values in the plane correspond to oscillations of increasing or decreasing magnitude with time. It should be noted particularly that values in the right half-plane correspond to oscillations which increase with time, while values in the left half-plane correspond to oscillations decreasing with time.

The general form of oscillation for a selection of points is shown in Fig. 8. If the ω co-ordinate of a general point is altered the frequency of oscillation changes proportionally to the change in ω while the magnitude variation which is controlled by the α co-ordinate is unaltered. Conversely the α co-ordinate affects the magnitude variation but not the frequency.

Complex values of p are always obtained and considered in conjugate pairs, which, when associated with each other, can be interpreted as a real oscillation; for instance

$$e^{(-\alpha+j\omega)t} + e^{(-\alpha-j\omega)t} = 2e^{-\alpha t}\cos\omega t$$

Thus any point in the plane that may be arbitrarily selected, or may be specified as the result of some analysis, defines a particular form of oscillation, and much of complex frequency analysis, and the root-locus method, can be interpreted as identifying points in the *p*-plane, or loci of point motion in the plane with variation of some parameter of a system.

Natural modes for a system with damping

If a complex frequency form of solution

$$x_o = X_o e^{pt}$$

is anticipated to the equation for the spring-mass system with damping

$$\frac{M}{K}\frac{d^2x_o}{dt^2} + \frac{C}{K}\frac{dx_o}{dt} + x_o = 0$$

substitution leads to

$$p^2M/K + pC/K + 1 = 0$$

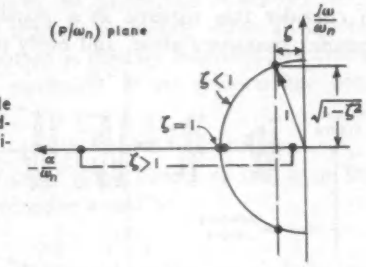

Fig. 9 Natural-mode positions for a second-order system with variation of damping ζ

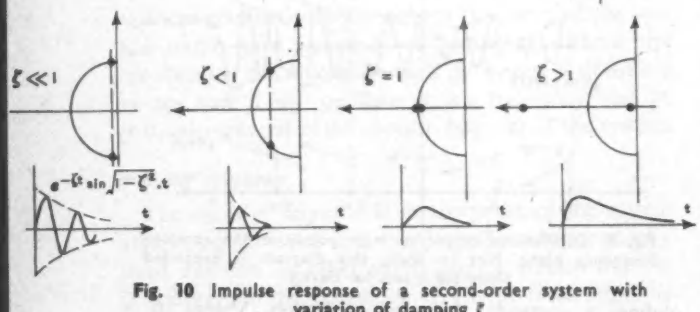

Fig. 10 Impulse response of a second-order system with variation of damping ζ

The natural frequency of the system in the absence of damping is

$$\omega_n = \sqrt{K/M}$$

which may be substituted to yield

$$\left(\frac{p}{\omega_n}\right)^2 + \frac{C}{\sqrt{KM}}\left(\frac{p}{\omega_n}\right) + 1 = 0$$

or

$$\left(\frac{p}{\omega_n}\right)^2 + 2\zeta\left(\frac{p}{\omega_n}\right) + 1 = 0$$

where

$$\zeta = \tfrac{1}{2}\frac{C}{\sqrt{KM}}$$

is the damping factor.

The final form of the equation may be solved to give roots

$$(p/\omega_n) = -\zeta \pm \sqrt{\zeta^2 - 1}$$

and these values define two forms of oscillation in the plane of a normalized complex frequency variable

$$(p/\omega_n) = (\alpha/\omega_n) + j(\omega/\omega_n)$$

For values of damping

$$\zeta > 1 \text{ or } C > 2\sqrt{KM}$$

the two solutions can be represented by points on the negative real axis, corresponding to non-oscillatory exponentials of the form

$$e^{(-\zeta+\sqrt{(\zeta^2-1)})t},\ e^{(-\zeta-\sqrt{(\zeta^2-1)})t}$$

while for

$$\zeta < 1 \text{ or } C < 2\sqrt{KM}$$

the solutions take the form

$$(p/\omega_n) = -\zeta \pm j\sqrt{(1-\zeta^2)}$$

giving complex points corresponding with oscillations

$$e^{(-\zeta+j\sqrt{(1-\zeta^2)})t},\ e^{(-\zeta-j\sqrt{(1-\zeta^2)})t}$$

representing a damped sinusoidal oscillation. For values of (p/ω_n) which are complex, the magnitude

$$|p/\omega_n| = \sqrt{(\zeta^2 + 1 - \zeta^2)} = 1$$

so that the path in the plane becomes a circle of unit radius centred at the origin as in Fig. 9. For large values of ζ one solution approaches the origin while the other approaches infinity along the negative real axis. If $\zeta = 1$, the two solutions coincide at $(\alpha/\omega_n) = -1$, and for smaller values of ζ the solutions are complex moving round the unit radius circle in the plane. Finally as $\zeta \to 0$ the two solutions approach the imaginary axis corresponding to undamped oscillations at the natural frequency of the system.

Impulse response for system with damping

If the impulse response for the damped system is investigated the general form is found to be oscillatory or non-oscillatory for $\zeta < 1$ or $\zeta > 1$, with critical damping for $\zeta = 1$, corresponding to coincident solutions at $(\alpha/\omega_n) = -1$ on the negative real axis. Fig. 10 shows the general form of the response for different values of ζ, together with solution locations in the plane. For large values of ζ the response is dominated by a slowly decaying exponential component corresponding to the solution close to the origin.

Conclusion

This article has attempted to emphasize some of the basic ideas leading up to complex frequency analysis and root locus methods. Initially the advantage has been considered of using inputs and outputs of the form $e^{j\omega t}$, as opposed to sine or cosine forms, when investigating the steady-state frequency response of a damped second-order system. However, when the *natural frequencies* or *natural modes* of such systems are considered it is found that constant-magnitude oscillations of the form $e^{j\omega t}$ must be extended to the more general form of exponentially increasing or decreasing oscillations represented by

$$e^{pt} = e^{(\alpha+j\omega)t}$$

or *complex frequencies* in order to cater for the modes of a damped system.

A basic essential of complex frequency analysis is to consider the frequency variable p in a plane, and to associate a particular form of oscillation with every point in the plane. Also the motion of solution points in the p-plane with parameter variation can be interpreted as representing changes in the forms of oscillation corresponding to the natural modes of the system.

References

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PART 3 There are still many outstanding problems of stability and control in the transient speed-range, but the reward for solving them will be great

Controlling v.t.o.l. aircraft at transition speeds

by **JAMES J. FOODY, M.SC., A.F.R.AE.S.**
Short Brothers & Harland Ltd

The problems of lateral, longitudinal, and hovering stability were discussed in Part 1, and in Part 2 last month we considered the forms of stability augmentation.

CONTROL

On conventional aircraft, control power is normally fixed by well-established criteria which cover trimming and manoeuvring requirements. Stabilizing forces are provided by the reaction of the air to the various aircraft movements in a disturbance. As speed is reduced into the transition range, both the power of the aerodynamic controls and the aerodynamic reaction forces themselves are reduced, in the limit tending to zero, so that in order to preserve some measure of control it is required to assist the aerodynamic surfaces with some form of reaction control. When this becomes necessary, not only is control power needed to trim and manoeuvre, but it must also be used to stabilize, either through the agency of the pilot or through an autostabilization system. Hence the question of control power on s.t.o.l. and v.t.o.l. aircraft introduces problems outside the range of present-day flight experience. These problems are critically examined below, and a comparison is made between those various v.t.o. aircraft flying in America on which information is available.

Conventional control function

Consider first the function of the various controls on a conventional aircraft. The function of the elevator is normally to provide a trimming moment in pitch and a normal acceleration. Hence the application of elevator from a trimmed position will initially cause an angular acceleration, and the aircraft will, assuming it is conventionally statically stable, settle at a new trimmed incidence (a motion normally referred to as the rapid incidence adjustment). This new incidence will in turn give rise to a normal acceleration which will continue until the speed changes significantly, or the power setting is adjusted to establish a new steady state. Thus as far as the pilot is concerned the effect of a given stick displacement is initially to produce a normal acceleration and a curved flight path. The application of ailerons, on the other hand, results in an initial angular acceleration, but the aerodynamic damping in roll soon produces a steady rate of roll. Hence, so far as the pilot is concerned, the effect of aileron application is to produce a steady rate of roll. The effect of applying the rudder is to initiate a turn and a steady slip; alternatively banking can be caused by use of ailerons, and a combined banking-and-yawing manoeuvre, in which angle of slide-slip is zero but rate of turn is finite, can be carried out.

Control in hovering

Turning to v.t.o. aircraft in a condition in which the aerodynamic forces can be considered negligible (i.e. speeds below say twenty knots), it is reasonable to expect that control will be provided about the pitch, roll and yaw axes. The application of these controls causes a simple angular acceleration about the axis in question. Hence, in place of controls which on the conventional aircraft are made *rate* controls by the influence of aerodynamic forces, we are faced with a set of *acceleration* controls, and without further consideration it is impossible to apply conventional experience. Furthermore, it does not immediately follow that the control power required is not a function of the degree of autostabilization installed, and initial efforts to get some experimental evidence on this subject were made on what is now known as the 'Duddy Rig'. This very simple apparatus represented the rolling control and its associated lateral movement, but no attempt was made to incorporate the pitch or height controls. It consisted of a vertical column, free to rotate about its axis, carrying a long arm with the model at the end, free to rotate about a horizontal axis. The model itself consisted of two fixed air-jets pointing downward, representing the lateral control of a jet-lift aircraft. This rig was used to determine both the amount of control power required and the feasibility of various stabiliz-

ing systems for both the Rolls-Royce 'Bedstead' and the S.C.1. It was estimated that an angular acceleration of 1 rad/sec² for full control power was adequate for an aircraft of the size of the Short S.C.1. The table below shows the comparison between the power available on various v.t.o. projects at the moment. The designs considered are not all strictly comparable, so the table should be read with some caution.

INITIAL ACCELERATION PER INCH OF CONTROL DISPLACEMENT

AIRCRAFT	PITCH	ROLL	YAW
Short S.C.1.	16°/sec²	21°/sec²	7°/sec²
Vertol 76	8°/sec²	25°/sec²	7°/sec²
Helicopters	8°/sec²	25–40°/sec²	6–20°/sec²
C-450	57·3°/sec² max.	57·3°/sec² max.	—

Criterion for control power in hovering

It has been observed that, in contrast to what is needed on conventional machines, v.t.o.-aircraft control power must be used both to stabilize and to manoeuvre, and both these functions are very tightly bound together. It is therefore to be expected that the control power

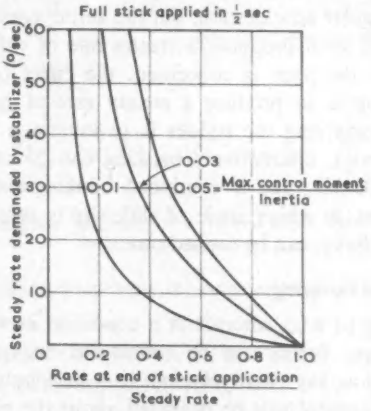


Fig. 13 Relation between steady rate of roll and growth parameter in hovering

needed is a function of the form of stabilization employed. Consider then the employment of a rate feedback alone for stabilization, and its analogous case on a conventional aircraft, the aileron control. Various amounts of rate feedback are possible, and sufficient flight experience does not, as yet, exist to determine an optimum. This may be in the range of 10°/sec to 30°/sec for full control. From the conventional experience it is also necessary to quote a rate-of-growth parameter, and this states that the rate of growth of rolling velocity shall be such that when aileron is applied in t seconds the rate of roll at the completion of the aileron application is not less than $p\{1-(1-k)(1-e^{-k})\}$, p being the steady rate of roll, $k = (tV\sqrt{\sigma})/2{\cdot}2w$ and w is wing loading.

It is obviously not possible to apply this criterion directly to the case of a v.t.o. aircraft, on account of the part played by the speed term; but examination of it has indicated that the rate of roll at the end of a typical aileron application, considered to last for ½ sec, lies in the range 0·3 to 0·5 of the steady rate of roll, depending on the speed and wing loading being considered. Fig. 13 shows the relationship between rate of roll at the end of a ½-sec stick application, as a ratio with steady rate of roll, and a parameter which fixes the amount of stabilization employed for different control : inertia ratios. The stabilization parameter is quoted as the resultant rate of roll for full stick application. It can thus be seen that if a rate-of-growth parameter in the range 0·3 to 0·5 is accepted, then the amount of control power necessary will be a direct function of the amount of stabilization required. Indications are that on a small aircraft an amount of stabilization corresponding to 25°–30° per second for full stick application is required; hence a control-power-to-inertia ratio of 0·04 is called for. For larger aircraft the required steady rate of roll during coventional experience will probably be reduced in proportion to span, hence the required control-to-inertia rate can be obtained from Fig. 13. Such a criterion is, of course, tentative, and will depend in the final evaluation on flight test experience.

Reaction controls

To date, the case of control power in hovering has been discussed, and clearly this requires some form of reaction control. Such controls can be provided by bleeding air from the engines and ducting it to nozzles placed at the extremities of the aircraft. A reaction force can thus be provided, proportional to the opening of these nozzles. An example of such a system is shown in Fig. 14. This nozzle is generally choked, and mass flow and reaction are proportional to nozzle opening. It is possible also to arrange lower-exit-velocity controls based on the fan principle, but this brings in its wake the further mechanical complication and increased weight involved in achieving the desired response characteristics, and the greater efficiency must be balanced against these disadvantages. In general, the basic design point on all reaction controls will be to ensure that the time lag is kept to a minimum, as this can have serious repercussions for both handling and stabilization.

Control at transition speeds

As speed builds up from the hovering condition, control power available from aerodynamic surfaces will increase in proportion to the velocity squared. Hence, even at small forward speeds, the contribution of aerodynamic surfaces is significant. The increase in aerodynamic forces also relieves the control of its stabilization function as the aerodynamic stability becomes increasingly more apparent. So for a v.t.o. aircraft the coupling of both aerodynamic and reaction controls to the stick is highly desirable, and the characteristics gradually change from those of hovering controls to those of conventional forward-speed controls. The major problem is how to ensure that an adequate margin of total control power over power to trim is available at all

stages of transition, and this is very much a function of the specific design.

For s.t.o.l. aircraft, on the other hand, the problem tends to have a different emphasis, the major question being what proportion of all-up weight can be taken on jets before it becomes necessary to assist the aerodynamic surfaces with reaction controls. This again is likely to be a function of the specific design, but flight experience on the S.C.1. will undoubtedly throw some light on the subject. Simulator experiments on a light aircraft of high-speed plan-form design have indicated that, for jet lift more than about 25% of all-up weight, some form of control augmentation is necessary, but flight experience in the transition speed-range will be necessary before any such conclusion can be drawn.

HANDLING CHARACTERISTICS

Much outstanding work has been done in the last twenty years on the measurement and definition of handling qualities of conventional aircraft, and the pioneering work of Gates and his associates at the R.A.E. established a sound theoretical and experimental background for the manoeuvring criteria of today. These play a very great part in the determination of handling characteristics, but do not paint the complete picture as some criterion for stability must also be involved. The three main elements which go to make up a pilot's judgement of his aeroplane's handling qualities are well summarized as follows:

1 The effort the pilot has to make, consisting almost entirely of stick force and stick displacement.
2 The behaviour of the aeroplane both when left to itself and when the controls are used. This is sensed visually and by the feel of the aeroplane's acceleration and response.
3 The time element: how quickly or slowly things happen.

There is no reason to believe that the same elements, where applicable, should not be used to assess the handling qualities of v.t.o. aircraft in the transition and hovering phases of their use. We have already discussed stability and stability augmentation; the problem of what amount of augmentation to employ in order to achieve adequate handling characteristics remains, and is treated below.

Handling in hover

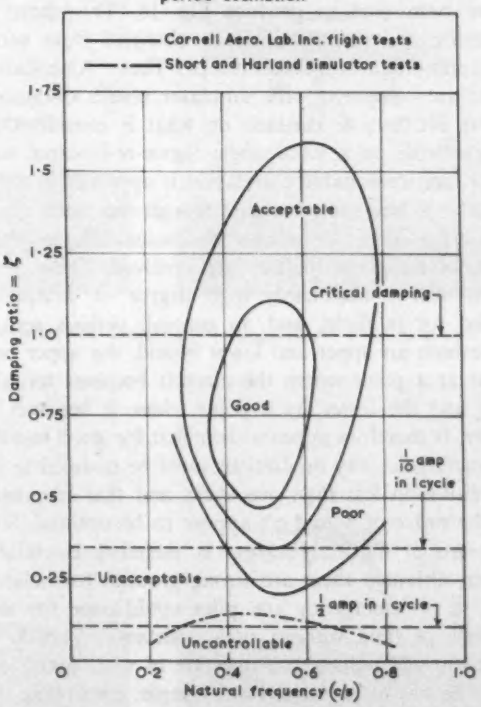
In looking at the elements on which handling requirements can be based it becomes immediately obvious that we can eliminate any undesirable stick force or stick displacement limitations in achieving good handling, and hence we will concentrate on the second and third elements quoted above. Considering first the hover, it is apparent that without stabilization the control about pitch, roll and yaw axes is of the acceleration type. Once stabilization is introduced, the designer can choose the form of control he considers most acceptable, and it is likely that this will be a function of the role of the aircraft. Thus for short-duration, fighter-type application there is no reason, as yet, to believe that a rate control will not be adequate, and for more sophisticated aircraft—or perhaps those in which blind landings are called for—there is little

Fig. 14 Control nozzle for Short S.C.1 autostabilizer

doubt that a more advanced form of stabilization will be called for. Simulator tests have led to the conclusion that pilots prefer as a minimum something closely akin to pure rate control, the feedback being such that full stick produces a steady rate of the order of 30°/sec.

As well as making sure that steady-state response to stick application is satisfactory, we must ensure that the oscillatory behaviour is acceptable; or in other words, the the frequency and damping is of the correct order. If rate feedback only is employed, the question of frequency arises only when sufficient aerodynamic forces are present to create an oscillation, but with

Fig. 15 Pilot opinion of handling in longitudinal short-period oscillation



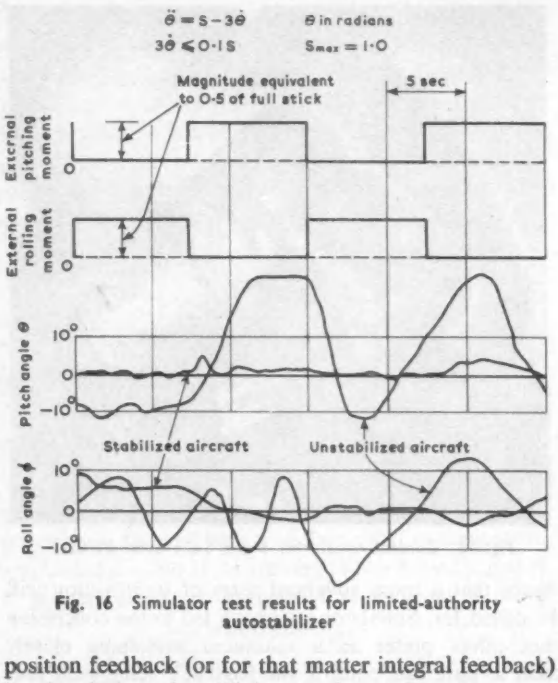


Fig. 16 Simulator test results for limited-authority autostabilizer

position feedback (or for that matter integral feedback) it arises in hovering. Flight experiments have been conducted in America to tie up the frequency and damping characteristics of various modes of flight, but it seems that desirable handling characteristics are largely a function of the particular mode, so the experience is not directly applicable to the case of v.t.o. aircraft. However, both the conventional short-period longitudinal oscillation and the conventional snaking oscillation have frequencies comparable to those found in a hovering v.t.o. aircraft, and results obtained from them have been used to produce Fig. 15. This shows the measure of handling efficiency obtained from various damping-frequency relationships. These American results are compared with simulator results obtained at Short Brothers & Harland on what is considered uncontrollable on a v.t.o. single-degree-of-freedom simulator, and reasonable correlation is apparent in the 0·4 to 0·6 c/s frequency range, although the trend outside this range seems to indicate that some different definitions of handling qualities are involved. These results show that a reasonably high degree of damping is called for in flight, and, in general, periods seem to have both an upper and lower bound, the upper being fixed at a point where the aircraft becomes too sluggish and the lower by a point where it becomes too lively. It therefore appears clear that for good handling characteristics any oscillations must be damped to half amplitude in less than one cycle, and that frequencies of the order of $\frac{1}{2}$ to $\frac{1}{3}$ c/s appear to be optimal. Some measure of autostabilization is therefore essential in hover, although there are strong grounds for believing that in an emergency any pilot could cope for short periods of time without such assistance. This in the long run will reduce to a question of what other functions he has to perform. For example, controlling one-degree-of-freedom (say) roll when pitch is autostabilized may not prove troublesome if the pilot does not need to devote any significant amount of attention to engine control, or even to ground instruction. Controlling both degrees of freedom simultaneously is likely to saturate his ability, and he may well be in no position to perform any other control function whatsoever

Lateral and directional handling

Once we leave the hovering regime, aerodynamic forces begin to play their part, and we have shown already that, irrespective of the design, as the speed falls off into the transition range on a v.t.o. or s.t.o.l. aircraft, a rapid deterioration in the Dutch roll stability takes place. At what speed such a characteristic becomes unacceptable is very much a function of the particular design, but for modern aircraft it seems unlikely that values of λ greater than about 0·4 will be possible without stability augmentation. Hence for s.t.o.l. aircraft any significant restriction in approach speeds may involve the necessity for autostabilization. For v.t.o. aircraft, on the other hand, stabilization is probably essential, and the degree of stabilization found desirable in hover on the roll control is likely to satisfy handling requirements at all transition speeds, so far as Dutch roll is concerned. There may be some difficulty with heading-holding characteristics, as the weathercock stability gradually fades out with decreasing speed, and this might well prove a significant embarrassment on a fixed-glide-path approach.

Longitudinal handling

As the speed is reduced there is no indication of any significant reduction in damping of the short-period mode, and the behaviour of phugoid period was shown in Fig. 7. On account of its longer period, however, it is unlikely that any unacceptable characteristics will result. Thus it could be argued that the requirement for a stabilizer is not so pressing in the longitudinal mode. It is probably essential in hover. The effect on stability at higher forward speeds, on the stabilizer provided for hovering, was shown under *Stability* earlier in this article.

Limited-authority autostabilizer

The characteristics and advantages of limited-authority autostabilizers were pointed out under *Stability augmentation*, and it was seen that, whilst the autostabilizer did some short-period work, quite a considerable amount of effort was still required from the pilot. The feasibility of this arrangement from the pilot's point of view has been studied on a simulator, and it can be seen from Fig. 16 that, with a conventional gearing and an authority restriction to 10% of full control power, the pilot's task in keeping the aircraft on an even keel in the presence of quite large disturbing forces is very much eased. Such a form of stabilization does of course introduce non-linearities into the control problem, but simulator evidence has not indicated that this is significant.

The use of a limited-authority autostabilizer involves the necessity to prove that, with a failure on one axis, the aircraft can still be handled. Again, of course, this is a function of the lag in the control circuit, and may well prove different from one aircraft to the next.

Height control

Flight experience to date has confirmed that, with certain limitations, height control on a v.t.o. aircraft is adequate. As already pointed out, this is an acceleration control, and it may still pay to introduce a measure of automatic control which will enable the pilot to hover without continuous attention to the lift throttles. This appears to be something of a refinement and more concerned with problems of specific control than stabilization. In a transition, where aerodynamic lift is being exchanged for jet lift as the speed decreases, continuous manipulation of the lifting throttles is essential, and their steady state, neglecting transient disturbance, is continuously varying with forward speed. Hence height control down a fixed glide-path, or even in level flight, is likely to prove difficult, and in certain conditions some form of automatic assistance may well prove necessary.

CONCLUSION

The possibility of vertical take-off using jet lift, or short take-off using either jet lift or various aerodynamic effects, has been adequately demonstrated by the test vehicles now flying both here and in America. It would be premature to assume that, with the demonstration of the principle, the way is clear to open up new operational applications. Many problems still exist, and amongst them can be numbered the general problem of stability and control in the transient speed-range. Some of these problems have been outlined in this article, and promising methods of solution have been indicated. It is hoped that extensive flight test experience will be gained in the near future, but anyone associated with flight testing—or for that matter design—will readily appreciate that it is more often the unforseen problems that prove most difficult in practice, and these will inevitably occur.

The reward for solving the outstanding problems will be great, as the v.t.o. field undoubtedly opens up a new era in both military and civil flying. The advantages in dispensing with conventional runways are considerable, but the major break-through may be elsewhere. The greatest single factor that is disrupting airline services at the moment is inability to land or take off because of weather. With the development of v.t.o.l., weather minima will become much less stringent, as the velocity at touch-down is of a different order, but all-weather landing will still depend on the provision of adequate and suitable landing aids. Perhaps, therefore, it is in the field of all-weather and regular operation that v.t.o. will make its major contribution to the future of flying, and this is undoubtedly a reward which would justify more and faster development than is presently being undertaken.

End

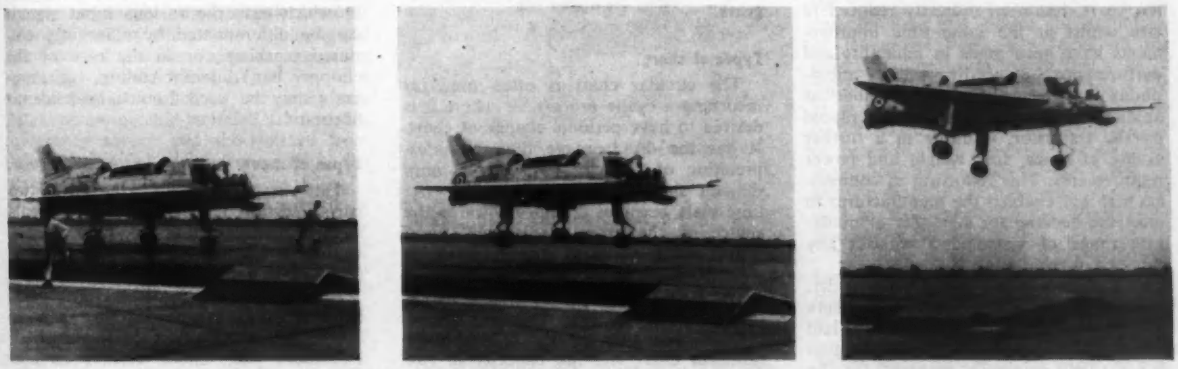


Fig. 17 Above and below are photographic sequences showing the Short S.C.1 in transition

CONTROL 18 SURVEY

Miniature recorders

by **J. R. SPENCER, B. SC**
British Petroleum Co. Ltd.

INCREASING ADVANCES IN INSTRUMENT technology and the wider use of instruments has led to the need in certain applications for smaller instruments without reduced standards of reliability. In the chemical and petroleum industries there is a trend towards centralized control of groups of plant, resulting in a larger number of instruments mounted per panel. The continual improvements being made in design and manufacturing techniques have enabled component manufacturers to offer a smaller but often more reliable component. The thermionic valve, for example, over the past ten years, has been radically reduced in size whilst at the same time improvements have been made in reliability and performance, especially where microphony is concerned. In a number of applications, the valve is being replaced by the transistor, resulting in a further saving of space, size, weight and power requirements. This reduction in component size has enabled the manufacturer to meet the demand for a smaller or miniature range of instruments without any sacrifice in reliability.

In the case of the miniature recorder, nearly all the models comply, where appropriate, with the requirements laid down in British Standard Specification B.S.90 : 1940 originally prepared for the larger recorders. This survey has been carried out on recorders with a chart width of 4 in. or less, manufactured in the United Kingdom, which are suitable for use in the process control field. It does not include specialized recorders, such as those used for registering on/off conditions, or those using special types of recording paper such as Teledeltos, ultra-violet, etc.

Chart drive mechanics

The chart is generally driven by either a synchronous motor or by a pneumatic impulse derived from a master clock, but in certain cases it is possible to obtain other forms of drive, such as the mechanical spring (clockwork) motor or an electrically wound clock. In the latter the drive is by an electrical synchronous motor fitted with clockwork reserve enabling the chart drive to be continued after removal of the main supply. The speed of most strip chart recorders will be one of those recommended in B.S.90: 1940, namely ¼, 1, 3, 6 and 12 in./h, or in./min. In addition to the above speeds, certain manufacturers are prepared to supply drives with a special speed. A number of recorders are fitted with multi-speed drives, in which case a change of chart speed may be effected either by operating a gear lever, a push button, or alternatively by a manual change of gears.

Types of chart

The circular chart is often used for recording a cyclic process, or where it is desired to have periodic change of chart. It has the disadvantage that the interpretation of the circular scale is more difficult than the strip chart, since the time scale becomes cramped towards the centre of the chart. Moreover, for a given width of chart it occupies considerably more panel space.

The strip chart recorder can, if necessary, be left for long periods; several models mentioned in the survey have sufficient chart and ink capacity to run for 30 days at a speed of 1 in/h without requiring attention. A number of manufacturers have arranged their recording movement with linkages to record on charts with rectangular co-ordinates (straight time-lines). This eases the interpretation of records and facilitates easy comparison between two or more records. Certain models are fitted with facilities for removing sections of the strip chart.

Method of marking

The two main methods of chart marking are by pen or chopper bar. The pen draws a continuous record and usually has a reservoir of ink compatible with the length of chart. Thus for strip chart recorders the supply of ink is in many cases sufficient for at least 30 days continuous running.

In the chopper bar the movement is periodically depressed by a clamping bar which marks the chart by means of an ink-impregnated ribbon. A typical time interval between successive markings is five seconds, and the record obtained will be a succession of markings generally in the form of dots. This type of recorder is therefore not suitable for recording inputs subject to fast fluctuations.

For both the pen and clamping bar it is possible to obtain multi-channel inputs, in which case the various input signals can be differentiated by differently coloured markings, or in the case of the chopper bar, different coding, e.g. numerals may be used for channel identification.

Types of movement

This survey has been arranged in two parts: section A deals with movements suitable for recording electrical signals, section B deals with the recording of pressure.

A number of recorder movements have facilities for zero adjustment to allow for drift that may be encountered. Recorders can, under certain circumstances, be fitted with suppressed scales, in which case the movement records over a limited range of input signals. This limited range need not include a true zero.

For temperature measurement, e.g. thermocouple and liquid-filled thermometers, it is possible to have automatic temperature compensation, whereby the recorder movement makes allowance for ambient temperature when recording.

The speed of response of a movement is generally quoted for full-scale deflexion, i.e. the time taken for the movement to travel across 62% of the width of the chart for a step input equal to the maximum signal of the span.

In the case of electrical inputs the movements will generally be one of the

following types—moving coil, induction, dynamometer (for power measurements), potentiometric, bridge or torque motor. An outline of some of the operations of these movements is given below.

Moving coil, induction, and dynamometer. These movements are basically the same as those used in the measuring instruments.

Potentiometric. The input signal is fed into one side of a balanced amplifier, a simplified circuit of which is given in Fig. 1. The output of each side of this amplifier is fed through a coil consisting of two equal windings wound in opposite

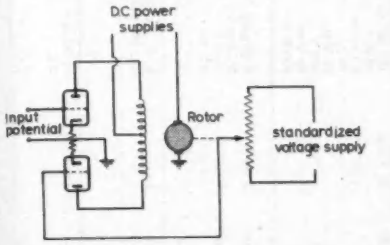


Fig. 1 Simplified potentiometric circuit

directions to produce magnetic fields of opposite polarity. Thus, if equal currents are flowing through both halves, no external magnetic field is produced, but unequal currents produce an external magnetic field, the polarity of which depends on which half has the greater current. A rotor situated in the external field and supplied from a d.c. source, will rotate whenever the output currents through the windings are unequal, the direction of rotation depending upon the polarity of the field. This rotor is mechanically coupled to the wiper arm of a potentiometer supplied from a d.c. reference source and the voltage from the wiper is fed back to one half of the amplifier.

When the input voltage, applied to one half of the amplifier, is unequal to the voltage fed back from the potentiometer, the unbalanced current in the coil results in the rotor moving until the feedback voltage equals the input voltage. The recording mechanism can be mechanically coupled to the rotor since the rotor position is related to input voltage. This type of movement is slower than the moving coil movement due to the larger inertia of the moving parts, but has the advantage that further potentiometers can be fitted for remote position indication. The potentiometric method of recording has a high input impedance and is often used where the input signal must not be loaded. As a general rule, the reference voltage to the potentiometer is periodically standardized against a Weston cell, or equivalent circuit using a Zener diode reference source.

Bridge method. In this the measuring element is arranged to form part of a bridge circuit (Fig. 2). The servo motor, instead of driving a potentiometer as in

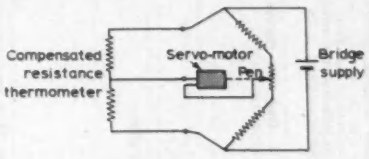


Fig. 2 Basic bridge circuit

Fig. 1, is arranged to drive the bridge to balance. This method is often used in conjunction with compensated resistance thermometers where the compensating lead and measuring lead form opposite arms of a bridge. In a majority of models the bridge is supplied from a d.c. source, but other models are available in which the bridge is driven from an a.c. source. In the latter case the servo amplifier has to incorporate phase-sensitive detection.

Torque motor. A typical circuit for measuring current and employing a torque motor is shown in Fig. 3. The input current passing through the coil attracts a beam. As the beam moves towards the coil it also reduces the air gap in the inductor increasing its impedance, consequently reducing the current drawn from the oscillator. The following stage is arranged so that the reduction in current drawn by the coil increases the current supplied to the torque motor. The resulting increase in torque from the motor increases the tension on the spring, which is partly taken up by the extension of the spring and partly by the force exerted on the beam,

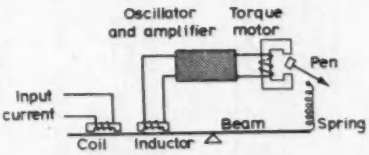


Fig. 3 Torque-motor circuit

the beam taking up a position of equilibrium. A pointer attached to the rotor arm gives an indication of input current.

Bellows and Capsule (Diaphragm). The diaphragm element consists of a thin metal disk, the material being chosen so that a differential pressure applied across the diaphragm will cause it to bow, the movement of the centre of the diaphragm giving an indication of the differential pressure. The sensitivity of the diaphragm can be improved by introducing corrugations and by placing two diaphragms back to back, sealing the circumference to form a capsule. The signal can be fed through the fixed centre of one side and the movement gives an indication of the differential pressure.

Alternatively, for extreme sensitivity, a stack, in which several diaphragms are mounted on each other and internally connected by means of a large aperture, can be constructed. The diaphragm stack is amongst the most sensitive of the pressure-measuring elements.

Where the sensitivity associated with a diaphragm stack is not required, bellows, which consist of a corrugated or concertina-shaped element can be used. It will be noted in the survey that a number of recorders using bellows are arranged for inputs over the range 3–15 lb/in²g. which is a standard range for process control instruments. Fig. 4 outlines a bellows movement. The force from the pneumatic signals causes the receiving bellows and spring to lift the horizontal arm pivoted on the bellows chamber. By adjusting the tension in the spring the range or span of the recorder can be altered. By means of a suitable linkage the arm can be arranged to operate on a graph with Cartesian co-ordinates.

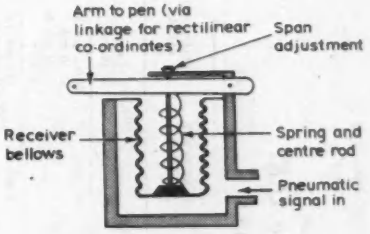


Fig. 4 Bellows movement

Bourdon. This system is often used in conjuction with liquid or gas-filled expansion thermometers. The Bourdon element consists of a hollow tube approximately elliptical in cross-section, and bent longitudinally to form the arc of a circle. As the pressure inside the tube increases, the cross-section tends to take up a circular shape, thereby setting up internal stresses which try to straighten the arc. If the tube is clamped at one end, the free end moves, the amplitude of movement being dependent on the differential pressures across the walls of the tube. Thus if a liquid or a gas is fed in at the fixed end, a pointer attached to the sealed free end gives an indication of pressure. This movement is generally magnified by increasing the length of tube so that the arc becomes a helix, and also by mechanical gearing fitted to the free end of the tube.

The tube is unfortunately sensitive to temperature but may be compensated for changes in ambient temperature by use of a bi-metal strip.

Other movements

The above descriptions are intended purely as an outline of the basic movements available, and it should be pointed out that there are a considerable number of variations and refinements on the above techniques. Inevitably, in a survey of this size, it is impossible to cover every type of movement, and a number, including those used for specialist measurements, such as the recording of frequency, have had to be omitted. For further information the relevant British Standards Specification (B.S.90:1940) and manufacturers' literature should be consulted.

Acknowledgement

The Author wishes to thank The Chairman and Directors of The British Petroleum Company Limited for permission to publish this paper.

Miniature recorders manufactured in the U.K.

SECTION A—ELECTRICAL INPUTS

MANUFACTURER	APPROXIMATE PANEL CUT OUT SIZE INCHES	APPROXIMATE SPACE REQUIRED ON PANEL INCHES	CHART DRIVE NOTIVATION	STANDARD CHART SPEEDS	CHART LENGTH	CHART WIDTH INCHES	METHOD OF MARKING	MOVEMENTS	RESPONSE F.S.D.	STANDARD RANGES	NOTES
	Width Height	*Width Height*									
Bailey ★ 487	$5\frac{7}{16} \times 5\frac{7}{16}$	$5\frac{13}{16} \times 5\frac{13}{16}$	Electrical	1 in./h.	80 ft.	4	Pen	Potentiometric	1 sec.	0–5 mV 0–10 mA	Dual-pen model available. Rectilinear co-ordinates on chart.
Dewrance ★ 488	$4\frac{1}{2} \times 4\frac{1}{2}$	$5\frac{1}{2} \times 5\frac{11}{16}$	Electrical	1, 3, 6 in./h	62 ft.	3	Pen	Torque motor	0·2 sec.	0–0·2 mA to 0–50 mA 0–20 mV to 0–10 V	Accuracy 0·5% of span. Double-pen model available. Used in Microsen control system. Model with 3-term controller available. Rectilinear co-ordinates on chart.
Electroflo ★ 489	$6\frac{1}{2} \times 6\frac{1}{2}$	8 × 8	Electrical	$\frac{1}{4}$ in./h. standard. Other speeds available.	30 days at $\frac{1}{4}$ in./h.	4	Pen	Potentiometric	8 sec.	0–5 mV to 0–600 mV	Accuracy ±0·5% of span. Transmitting slide-wire. Intrinsically safe external circuit. Dual-pen model available. Forms part of Electroflo control system. Model with 3-term controller available. Rectilinear co-ordinates on chart.
Electro Methods ★ 490	$6\frac{1}{2} \times 3\frac{1}{2}$	$6\frac{1}{2} \times 3\frac{1}{2}$	Clockwork			2	Pen	Servo (potentiometric)		0–10 mV	Weight of recorder is 4½ lb with batteries sufficient for 100 h. running. Resolution claimed to be 1% full scale.
Elliott ★ 491	4·825 × 10·125	5·625 × 11·63	Electrical, Clockwork	1, 2, 3, 6, 30 in./h. Dual speed model with lever change available. 1000 in./h. electrical only	65 ft.	3	Pen	Moving coil Moving coil rectifier	0·13 to 1·5 sec.	0–40 mV to 0–600 V d.c 0–0·5 mA to 0–50 A. 0–5 V to 0–600 V a.c. 0–0·5 mA to 0–25 A a.c.	Multi-pen models available. Each pen records on separate chart.
Evershed ★ 492	4 × $5\frac{13}{16}$	$4\frac{1}{2} \times 6\frac{1}{2}$	Electrical	$\frac{1}{2}$, 1, 3, 6 in./h; 10 mm and 20 mm/h. Dual-speed model available.	33 ft.	2	Chopper Bar	Potentiometric	0·8 sec. Rate of marking= 12 marks per minute	Sensitivity 1 mA with 250 Ω resistance. 10–A and 500–V maximum self-contained ranges	Rectilinear co-ordinates on chart.
Everett Edgcumbe ★ 493	$6\frac{7}{8} \times 6\frac{1}{2}$	$7\frac{1}{2} \times 7\frac{1}{2}$	Electrical, Clockwork Spring driven electrically wound	$\frac{1}{2}$, 1, 3, 6, 12 in./h. $\frac{1}{2}$, 1, 3, 6, 12 in./min. $\frac{1}{8}$, $\frac{1}{2}$, 1, 2, 4 in./sec. Electrical drive only.	65 ft.	4 and 2½	Pen	Moving coil dynamometer Induction Moving coil rectifier	0·1 sec. to 3 sec.	0·15 mA to 100 mA to 10 A 0·5 A to 10 A 50 V to 450 V 50 V to 500 V	Accuracy to B.S. 90:1940. Multi-range and multi-pen models available. Many other standard ranges available, including power measurement from 0·16 mW upwards.
Fielden Strip Chart ★ 494	$7\frac{15}{16} \times 5\frac{13}{16}$	$7\frac{1}{2} \times 6$	Electrical	1 in./h.	30 days	4	Pen	Potentiometric	1 sec.	0–15 mA 3–15 mA	Accuracy ±0·5% f.s.d. Used in Fielden control system. Model with 3-term controller available. Rectilinear co-ordinates on chart.
Circular Chart ★ 495	$8\frac{5}{16} \times 7\frac{1}{2}$	$7\frac{5}{16} \times 8\frac{1}{2}$	Electrical	1, 1/12, 1/24 rev/h. 1 rev. in 7 days.		3½ in. (Chart Radius)	Pen	Potentiometric	1 sec.	0–5 mV	
Firth Cleveland ★ 496		$7\frac{7}{8} \times 5\frac{1}{2}$	Electrical	$\frac{1}{2}$, 1, 2, 3, 6, 12 in/h. Multi-speed model available.	Over 60 ft.	3	Pen	Potentiometric	1 sec.	1, 5, 10, 20, 50, 100 mV	Accuracy 0·1% with a minimum of 0·005 mV. Multi-range model can be supplied. Uses Zener diode standard voltage reference source. Can be fitted with transmitting slide-wire. Rectilinear co-ordinates on chart.
Foxboro-Yoxall ★ 497	6 × 6	$6\frac{13}{16} \times 6\frac{1}{2}$	Electrical Mechanical Pneumatic	$\frac{1}{2}$ in./h.	Over 45 ft. (30 days running at std. speed)	4	Pen	Torque motor	1 sec	10–50 mA d.c.	Two-pen model available. Part of Consotrol control system. Can be fitted with 3-term controller.
Honeywell	5½ × 6	$5\frac{13}{16} \times 7\frac{1}{16}$	Electrical	½, 1½, and	53 ft.	4	Pen				

Foxboro-Yoxall ★ 497			Mechanical Pneumatic								(Pneumatic timing at std. speed)
Honeywell ★ 498	5½ × 6	5$\frac{13}{16}$ × 7$\frac{3}{32}$	Electrical	½, 1½, and 3 in./h.	53 ft.	4	Pen	Torque motor		4–20 mA	Accuracy ±0·5% of span. Part of Tel-o-set system. Can be fitted with 3-term controller. Dual model available. Rectilinear co-ordinates on chart-pen.
J. Langham Thompson ★ 499	5·9 × 7·7	9·4 × 6·7	Electrical	0·8 in./h.	50 ft.	3·9	Chopper-bar	Potentiometric	5 sec.	0–5 mV to 0–100 mV	Accuracy ±0·5%. Multi-range model available. Part of Electrofact control system. Available with transmitting slide-wire and alarm contacts.
Mervyn ★ 500	6 × 6	7 × 7	Clockwork	1/25 in./h. to 6000 in./h.		4	Ink or wax paper	Potentiometric	1 sec.	0–5 mV to 0–1 V	Accuracy better than 0·5%. Mains or battery (portable) model available. Zener diode voltage reference source.
Record ★ 501	5·13 × 6·5	5·6 × 7·317	Electrical Clockwork	½, 1, 2, 3, 6, 12 in./h. or in./min. Dual-speed model available	65 ft.	3	Pen	Moving coil Rectified moving coil	0·2 to 0·8 sec.	0–0·1 mA to 0–50 A 40 mV to 800 V 0–0·5 mA to 0–30 A 0–25 V to 0–800 V	Induction (a.c.) ammeter, voltmeter, wattmeter and frequency recorder also available. Multi-pen model available, each pen having separate chart.
Sunvic (A.E.I.) ★ 502	6 × 6		Electrical Pneumatic	1 in./hr.		4	Chopper and continuous	Potentiometric	3 sec.		Transmitter slide-wire. Rectilinear co-ordinates on chart.
Swartwout (Elliott) ★ 503	5 × 5	7 × 7½	Electrical	6 in./h. 1 in./min.	Over 62 ft.	3	Pen	Differential transformer	1 sec.	0–5 V 50 c/s	Accuracy ±0·5% f.s.d. Rectilinear co-ordinates on chart. Part of Swartwout control system. Can be fitted with 3-term controller.

SECTION B—PRESSURE INPUTS

MANUFACTURER	APPROXIMATE PANEL CUT OUT SIZE INCHES	APPROXIMATE SPACE REQUIRED ON PANEL INCHES	CHART DRIVE NOTIVATION	STANDARD CHART SPEEDS	CHART LENGTH	CHART WIDTH INCHES	METHOD OF MARKING	MOVEMENTS	STANDARD RANGES	NOTES
	Height Width	*Height Width*								
Bristol ★ 504	4$\frac{15}{16}$ × 4$\frac{15}{16}$	5½ × 5	Electrical Pneumatic	1 in./h.	65 ft.	3	Pen	Bellows	3–15, 5–25, 3–27, 0–30, lb/in.²g.	Accuracy ±0.5% f.s.d. Rectilinear co-ordinates on chart. Forms part of Metagraphic control system. Can be fitted with 3-term controller.
Cambridge ★ 505		2½ (dia.)	Clockwork	1 rev. per 2, 12, or 24 h.	Approx. 8 in.	1½ (40 mm.)	Pen	Bourdon	Minimum span of 50°F.	Temperature measurement only. Drum chart. Accuracy of Minicam—1.25% f.s.d.
Electroflo ★ 506	6½ × 6½	8 × 8	Electrical Pneumatic	½ in./h.	Lasts 31 days at standard speed	4	Pen	Capsule	3–15 lb/in²g.	Dual-pen model available. Rectilinear co-ordinates on chart. Forms part of Electroflo pneumatic control system. Can be fitted with 3-term controller.
Fischer & Porter ★ 507	5$\frac{13}{16}$ × 5$\frac{7}{16}$	7½ × 6	Electrical Pneumatic	¼ in./h.	Lasts 31 days	4	Pen	Capsule or Bourdon	3–15, 0–20 lb/in²g.	Dual-pen model available. Rectilinear co-ordinates on chart. Can be fitted with 3-term controller. Part of Ratographic control system.
Foxboro-Yoxall ★ 508	6 × 6	8½ × 7	Electrical Pneumatic	½ in./h.	Lasts 31 days at standard speed	4	Pen	Bellows	3–15 lb/in²g.	Dual-pen model available. Rectilinear co-ordinates on chart. Part of Pneumatic Consotrol system. Can be fitted with 3-term controller.
Honeywell ★ 509	5$\frac{1}{32}$ × 4$\frac{9}{16}$	5$\frac{31}{32}$ × 5	Electrical Pneumatic	1 in./h.	30 days	3	Pen	Bellows	3–15 lb/in²g.	Dual-pen model available. Rectilinear co-ordinates on chart. Part of Tel-o-set system. Can be fitted with 3-term controller.
Sunvic ★ 510			Electrical Pneumatic	1 in./h.	30 days	3	Pen			
Taylor ★ 511	6½ × 6½	8½ × 8½	Electrical Pneumatic	1 in./h., also 3, 6, 12, 30 in./h. 1 in./min.	31 days	4	Pen	Pneumatic servo	3–15 lb/in²g.	Dual-pen model available. Rectilinear co-ordinates on chart. Part of Transitrol control system. Can be fitted with 3-term controller.
	5$\frac{1}{32}$ × 4$\frac{9}{32}$	6½ × 6½	Electrical Pneumatic	1 in./h.	31 days	3	Pen	Bellows	3–15 lb/in²g.	Part of Transet control system.

For further details circle appropriate number on reply card facing page 194

Further discussion of topics from the J.A.C. Conference reported last month, and a report on the Annual Conference and Exhibit of the I.S.A., are included in this news-letter from our special correspondents in the United States

Look at America

This month : I.S.A. Conference—saturating systems—process dynamics

I.S.A. annual meeting

The Fall Instrument Automation Conference and Exhibit of the Instrument Society of America* was held September 26–30 in New York City. Over three hundred exhibitors displayed their wares on three floors of the Coliseum, and a program including over 125 technical papers was held in conference halls and rooms in the Coliseum and the New Yorker Hotel.

Opened by a Keynote Session and National Lecture Series on Monday, the program included an Education Forum, four Workshops (User-Management, Data Handling, Standards and Measurement Laboratories, and Educators'), a Computer Clinic and a host of technical sessions.

The general topic of underwater instrumentation was very well covered by 24 papers given in six sessions. It was evident that rapid developments are taking place in this field and that a very wide variety of problems is being solved. Although a few military problems were discussed relating to the operation of mines and submarines, most of the papers dealt with general problems such as measuring ocean floor conditions; navigation with the aid of position markers; measurement of ocean water conditions; remote handling techniques in deep water; identification of underwater objects; bathyscaphe design; and underwater cables.

The topic of strain gauge instrumentation was thoroughly covered by eleven papers given in five sessions. Conventional bonded-resistance strain gauges were involved in six papers which dealt with such problems as temperature effects, short damping-time without transverse sensitivity, standards for characteristics, adhesives, and a novel digital potentiometer for precision measurements with strain gauges. One paper dealt with an unbonded strain gauge pressure transducer, and another with a new type of resistance foil strain gauge for concentrated stress analysis. Three papers dealing with semiconductor strain gauges evoked a great deal of interest with claims for much greater sensitivity than with conventional gauges. One device, said to consist of 'silicon semiconductor whiskers in a micro-sensitive instrumentation device', was said to be 50–60 times more sensitive than its metallic counterpart.

* See also 'Progress through Instrumentation', a more detailed account of the Conference by *Control's* Consultant Reginald Medlock, on page 86 of this issue—EDITOR.

Optimal design of saturating systems

At the recent J.A.C. Conference considerable attention was given to the analysis of saturating systems, i.e., systems having either a bang-bang element or an idealized saturating element which is used to drive the plant. Fig. 1 illustrates, in a very general way, the type of system discussed (*1*). The system is of the *n*th order, the saturation element includes a proportional region of operation, and the computing device in general performs a non-linear operation on the incoming variables. The important restrictions on generality are the assumption of a linear plant and the absence of any feedback function operating on the output variables. If the plant is overdamped, i.e. its eigenvalues are all negative and real, formulation and analysis are made considerably easier than in the case where complex roots are present. Nevertheless, it is still rather forbidding.

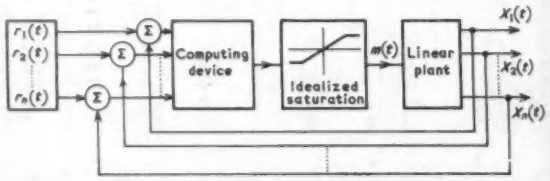


Fig. 1 General block diagram of a saturating system

Most authors at the conference who dealt with the class of system represented by Fig. 1 found it necessary to use mathematical analysis quite removed from the conventional Laplace-transform or describing-function methods, since these techniques are too restricted in application to describe the system behaviour effectively.

Instead, analysis is performed in the time domain. For an *n*th-order system, the output is completely described at any instant by the value of the output itself and its $n-1$ derivatives. Considering this, it is possible to let the output of the system be represented by a corresponding *n*-dimensional vector, whose co-ordinates take on the values of all the derivatives of the output variable. The vector space thus generated is referred to as the state space, and the 'distance' of the vector point from the origin of the state-space co-ordinate system represents exactly how far the system is from correspondence with the reference input. Note that correspondence here means that the system error and all its derivatives are simultaneously zero.

Thus, referring to Fig. 1, the equation describing the linear plants is (*1*)

$$[\dot{X}(t)] = A[X(t)] + m(t)[f] \qquad (1)$$

$[X(t)]$ = vector representation of the state of the plant at time t

$A = n \times n$ matrix describing the plant

$m(t)[f]$ = vector representation of input to the plant

The solution of Eq. 1 is given as

$$[X(t)] = G(t)[X(0)] + \int_0^t m(\tau)G(t-\tau)[f][d\tau] \qquad (2)$$

where

$[X(0)]$ = initial state of plant

$G(t)$ = impulse response matrix of plant and the input to the system is identically zero

For these systems the problem of optimization consists in finding the proper function $m(t)[f]$ such that $[X(t)]$ reaches zero in minimum time. It has been shown

that one necessary condition for optimization is that $|m(t)| = 1$, which means that the proportional band in the saturable element should be eliminated; hence the controller action would be that of a pure relay, exerting maximum effort (+ or −) on the plant at all times. In addition, for an overdamped plant, exactly $n - 1$ switchings are necessary to attain equilibrium (*2*).

However, this is not to say that a shorter settling time could not be obtained if proper operations were performed on the feedback signal. Systems of this type were not considered in general terms by any of the authors.

Several of the papers presented were principally concerned with finding the optimal form of $m(t)[f]$, which is called the switching function, and which is represented by the 'computing device' in Fig. 1.

In the paper by Kurzweil (*1*) it is shown that the desired solution depends on solving equations of the form

$$-[X](0) = [X]_{i-1} + (-1)^{i-1} m_1 \int_{t_{i-1}}^{t_i} G(-\tau)[f][d\tau] \quad (3)$$

$[X]_{i-1}$ = state of output during the $(i-1)$ switching interval

$m = \pm 1$

Since a closed form of solution is not obtainable, a scheme is presented for machine computation of the switching function. The computation logic is similar to that found in certain sampled-data techniques, and requires *n*th-order data storage. The computer solves Eq. 3 step by step, generating the switching function from interval to interval. Specific computer logic and results for a third-order plant controlled in this manner are presented.

The optimum solution to a much more specific system is sought in a paper by

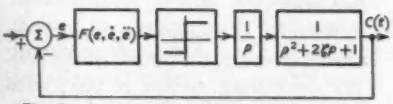


Fig. 2 System discussed by Flügge-Lotz and Yin

Flügge-Lotz and Yin (*3*). Their system, shown in Fig. 2, is simplified in that it is characterized by a second-order operator in series with an integration, but is of great interest since the authors have chosen to consider the case of complex roots ($\zeta < 1$). For this case the switching function is a very complicated-shaped, three-dimensional surface. It is shown how projections of this surface in a two-dimensional plane can be obtained, and further, an iteration procedure is presented which allows that projection which represents the optimum solution to be found. Methods of solution when $\zeta = 0$ and $\zeta \neq 0$ are discussed, and specific examples are given for demonstration.

As was mentioned previously, seeking an optimum solution for an on-off control scheme implies that the input to the system is held constant at some prescribed value. When ramp inputs are considered, the analysis is complicated by the fact that the slope of the input becomes another variable to be taken into account. This problem was discussed by Farrah in application to the system shown in Fig. 3 (*4*).

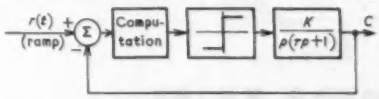


Fig. 3 System discussed by Farrah

Since only a second-order plant is involved, a two-dimensional phase-plane plot is sufficient completely to describe system behaviour. The difficulty arises in that the trajectories in the phase plane are unique only for a given slope of the ramp input. Therefore this slope must be taken into account when computing the switching boundary. The proper logic for accomplishing this computation is presented. It involves a continuous calculation of the switching boundary that accounts both for the slope of the input ramp and the existing output velocity. The scheme always brings the system to zero error in two switchings, but it is not shown that the logic involved guarantees a minimum-time solution.

Under certain conditions it is known that on-off control systems, with small-amplitude inputs, will exhibit very-high-frequency switching, but with large-amplitude inputs will behave according to normal switching behaviour as discussed up to this point. Halstenberg (*5*) has developed a very simple criterion that determines in which mode a third-order system will operate. Here again a vector description of the system's output is used. This output state vector is compared with the vector representation of the surface in which high-frequency switching occurs. A simple comparison indicates whether or not the state vector is forced to remain in the switching plane, thus giving rise to the high-frequency oscillations.

Chemical process dynamics

Rapid advances in the field of self-optimizing and adaptive control systems for chemical process plants have perhaps overshadowed the equally important work in chemical process dynamics. Of course, the age-old problem of having an inadequate understanding of the physical process to be controlled still exists. The inability to establish mathematical models of many real physical processes has seriously hindered the development of sophisticated control schemes.

Recently the Research Subcommittee of the Instruments and Regulators Division of the American Institute of Mechanical Engineers met to consider the present state of knowledge of process dynamics in relation to equipment design. They decided that little or no correlation existed between observed control loop behaviour (as determined from large amounts of response data) and the physical design of systems. Interestingly enough, one theory suggested that the lack of correlation was due to improper mathematical representations of the physical systems. In view of recommendations by the Subcommittee, Williams and Morris (*6*) have prepared a survey and critical evaluation of the literature on heat-exchanger dynamics and control. The survey indicates a necessity for an adequate theoretical basis for the evaluation of experimental results.

Other unrelated but important efforts have also been made to evaluate critically the level of understanding of chemical process dynamics. Lapidus (*7*) presented a paper at the recent J.A.C. Conference that reviews the current status and the possible future directions of chemical reactor dynamics. Primary concern is in the simulation and/or computation of the behaviour of various types of chemical reactors.

A very exhaustive summary and evaluation of the literature concerned with the dynamics and control of distillation units and other mass transfer equipment was presented at the J.A.C. Conference by Archer and Rothfus (*8*).

Your American Correspondents

J. LOWEN SHEARER, ROBERT S. SCHER, KARL N. REID, JR.

Massachusetts Institute of Technology

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A monthly review—under basic headings—of the latest control engineering developments for all industries; specially edited for busy technical management, plant and production engineers, chemical engineers, etc., who are not specialized in instrument and control systems

IDEAS APPLIED . . .

. . . to DATA HANDLING

Long-term storage of analogue information

A. M. ANDREW, National Physical Laboratory

For the non-digital storage of quantitative information the electrical capacitor has a number of advantages. The stored quantity can be read out with virtually no disturbance of its value, and it can readily be modified by the addition or subtraction of charge. The amount of the modification can be made to depend on the value previously stored. This feature is useful where the requirement is to integrate a sequence of input values with an exponential or other weighting function.

A simple capacitor is, however, unsuitable for long-term storage since a certain amount of leakage is unavoidable. The storage system described here incorporates a capacitor and embodies the desirable features of capacitor storage; it has the additional advantage that there is no drift of the stored quantity during any period when it is not required to modify its value to take account of new information.

The device incorporates two systems in which the position of a moving part is determined by an electrical signal. The two systems may, for example, be moving-coil meter movements, as shown in Fig. 1.1. One of these, movement *A* in Fig. 1.1, is connected so that the position of its moving part depends on the charge on capacitor *C*. The other, termed movement *B*, has attached to its moving part a clamping device. The positions of the two moving parts are sensed in some manner which produces a signal determined by the position of one relative to the other. Methods of comparison which could be used include electrical contacts on the moving parts, photo-electric methods, and methods depending on variations in inductance or capacitance due to relative movement. The method of comparison illustrated depends on the variation of capacitance between metal vanes attached to the moving parts.

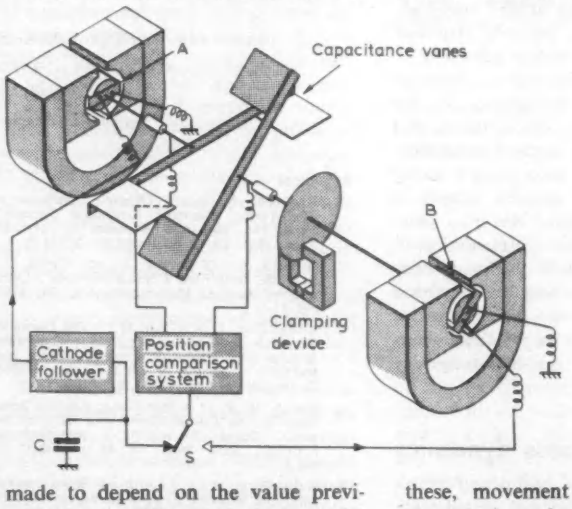


Fig. 1.1 Schematic diagram of the storage system, using capacitance vanes for position comparison

During a period when it is not required to modify the stored quantity, movement *B* is clamped, and the output of the position-comparing system is applied to capacitor *C* in such a way that it produces a negative-feedback loop which causes the position of movement *A* to be governed by that of the clamped movement *B*. The feedback loop incorporates capacitor *C* and, therefore, leakage in *C* is compensated.

When it is required to modify the stored quantity, the output of the position-comparing system is transferred by switch *S* so as to actuate movement *B*. The clamping device is then released. The feedback is then such that *A* and *B* are maintained in the same relative positions as before. The stored quantity represented by the charge on *C* can then be modified, by circuits not shown in the figure, exactly as though simple capacitance storage had been used.

When the modification is complete and a short time has elapsed to allow movement *B* to settle, the clamp is reapplied, and the output of the position-comparing system again applied to capacitor *C*. The modified quantity is then stored without drift.

An experimental storage device of

this type has been demonstrated, and the method forms the subject of U.K. Patent Application No. 11072/60. The author is indebted to Mr P. Müller for assistance with the electronic circuitry, and to the Director of the National Physical Laboratory for permission to publish this description.

. . . to FLOW

Fuel mass flowmeter

A new type of aircraft fuel meter, giving a direct measurement of the mass of fuel passing, has been developed from a Bendix design by Elliott Brothers (London) Ltd. The transmitting element of the system produces a signal representing the torque required to impart a known angular velocity to the fuel, this torque being proportional to the mass flow.

Fig. 2.1 illustrates the principle of the transmitter. The concentric cylinders *A* and *B* rotate in the casing *C*, which is effectively an enlarged section of the pipe-line. Cylinder *A* is driven at constant speed by a synchronous motor and a gear-box (not shown in the diagram). The motor and gear-box are housed in a sealed chamber mounted concentrically in the casing *C*, a magnetic coupling being used to transmit the drive through the sealed chamber to cylinder *A*. Cylinder *B*, which forms the outer shell of an impeller, is driven by cylinder *A* through the spring *D*.

The two rotating cylinders and the casing *C* are made of non-magnetic material, and are machined to close tolerances to reduce leakage paths through the impeller system to negligible proportions. Thus virtually all the fuel flows through the internal segments formed by radial vanes inside cylinder *B*. These vanes impart an angular velocity to the fuel passing through them. The reaction to the torque exerted by the vanes causes *B* to lag *A* by an amount depending on the mass of the fluid being accelerated.

In order to generate a signal representing the angle of lag between *A* and *B*, a transformer-type pick-off is used. Iron strips, *E* and *F*, are attached to the circumferences of *A* and *B* respectively, each covering approximately 180° of arc. The arrangement is such that at zero flow an almost complete circle of magnetic material is formed. During rotation, the two iron strips vary the coupling between the coils of the externally mounted pick-off transformer *G*.

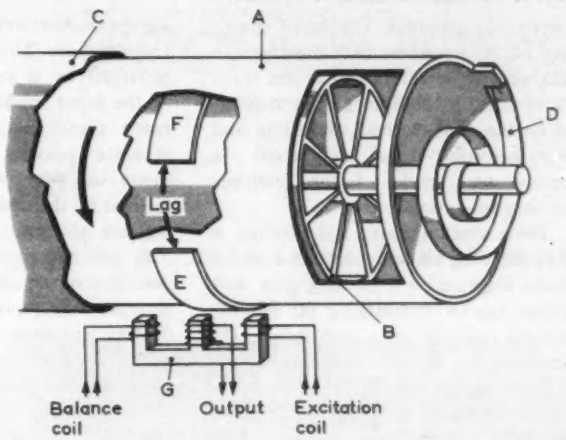


Fig. 2.1 Schematic diagram of the transmitter. The rotating cylinder A drives the impeller B through the spring D

The output from this transformer will, at any given time, have an amplitude which depends on the coupling provided by the iron strips. Fig. 2.2 shows a typical output waveform. It consists of a 400 c/s carrier wave modulated to three distinct amplitudes. The smallest amplitude represents the period when neither strip is providing coupling; the large and intermediate amplitudes represent the periods when *E* and *F* provide the coupling respectively. While *E* is influencing the coupling, amplitude of the output wave is independent of the position of *F*.

As the strips are 'out-of-phase' when there is no flow, the duration of the low-amplitude portion of the wave is a measure of the lag between them, and consequently of the mass-flow.

The output signal from the transmitter is taken to a computing unit which converts the signal to a form suitable for operating an integrator and rate-of-flow indicators. Briefly, the methods employed are as follows.

For rate-of-flow indication, a potentiometer coupled to the indicator pointer produces a voltage proportional to the indicated value. This is converted to a series of rectangular pulses, of duration proportional to the potentiometer voltage, by comparing it with a ramp voltage which is started at a time corresponding to the point *P* on the transmitted signal (Fig. 2.2); the duration of each pulse is the time required for the ramp voltage to reach the value of the potentiometer voltage. The length of the pulses derived from the indicator in this way is compared with that of the pulses of the mass-flow signal from the transmitter, any difference producing a signal to correct the indicator reading.

To obtain the integrated value of the flow, 400 c/s pulses are counted during the period of the rate-of-flow signal. As the cylinders are being driven at constant rev/min, the sum of these pulses over any period is proportional to the total fuel passed. The pulse count is divided so that each output pulse to the integrator represents one mass-unit of fuel.

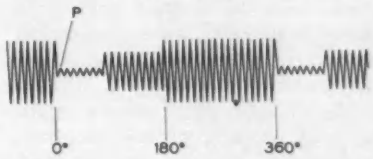


Fig. 2.2 Typical output waveform from transmitter. The duration of the low amplitude portion of the wave is proportional to the mass flow

. . . to SERVO-TESTING

Assessment of performance using simple equipment

J. D. LOCKE and W. G. PHILLIPS, B.Sc., Philco International

Recently the authors were faced with the problem of assessing the performance and demonstrating the properties of servo systems designed for instructional use. This involved showing the effect on the servo performance of each of the variables in the servo equation and rapidly comparing the results. It was felt that, for both sales demonstration and production testing,

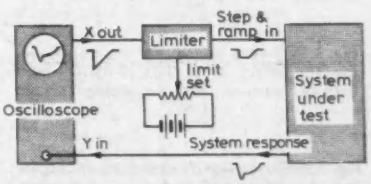


Fig. 3.1 Use of oscilloscope to provide a 'step plus ramp' input

speed was essential. The rapid changing of the variables had already been allowed for in the design of the servo demonstration equipment, but to determine the best method of testing and demonstrating the equipment a review was made of the practices already in common use.

These methods are: (1) plotting a Nyquist diagram; (2) plotting a phase plane diagram; (3) plotting gain and phase against frequency; (4) obtaining the response to a step input; (5) obtaining the response to a ramp input.

Methods (1) and (3) are slow, even with automatic plotting equipment, especially where low natural frequencies are encountered. Method (2) can be done rapidly using a repetitive step, but it was felt that the presence of noise and ripple on the velocity signal made the resulting diagram dificult to interpret. Even with a perfect velocity signal the implications of the diagram are not obvious.

Method (4) is rapid, using a repetitive step, but tells only half the story. The results, however, permit rapid interpretation and qualitative appreciation. Method (5) tells the other half of the story, but when d.c. sensing elements are used these can only operate for a short time before their limits are reached. The ramp is normally provided by a constant speed drive to the input, making variation of the ramp speed inconvenient without a separate velocity servo. The great merit of this method is that, like method (4) the results (e.g. the velocity-lag) are obvious.

It was therefore decided to use a combination of methods (4) and (5). A limit was imposed on the amount of test equipment used, in order to make it easily transportable and to avoid diverting equipment booked for other purposes. The method devised has since proved so effective that it was felt that it might be of interest to others working in this field.

First a source of step and ramp inputs was required. Secondly, the servo output was to be displayed on an oscilloscope so that a rapid appreciation could be made of the result. As this involved synchronizing both ramp and step to the trace, the sweep waveform of the oscilloscope, suitably modified, was used to provide both inputs. The layout of the equipment used is shown in Fig. 3.1.

The sweep output of the oscilloscope is fed to a series diode limiter where the limiting level is set to control the step amplitude. The combined step and ramp is fed to the servo and its output displayed on the oscilloscope. The servo response is automatically synchronized to the trace, and the ramp remains at the same angle on the trace when the sweep speed is switched. This latter quality is extremely useful when measurements are to be taken of the velocity-lag for different ramp speeds, i.e. different sweep speeds, as the reference line remains fixed. Using a long persistence tube and switching the sweep speed gives a series of parallel traces showing this effect. When showing the use of transient velocity-feedback or error rate damping, the presence of the step also shows how the damping has been affected, as the capacitors involved are connected in the circuit.

The eight accompanying oscillograms (Fig. 3.2) demonstrate the versatility of the method. The responses shown were obtained from a servo-system designed specifically for demonstration purposes. It covers six types of basic system and permits the rapid alteration of thirteen linear and non-linear variables affecting the performance of the system.

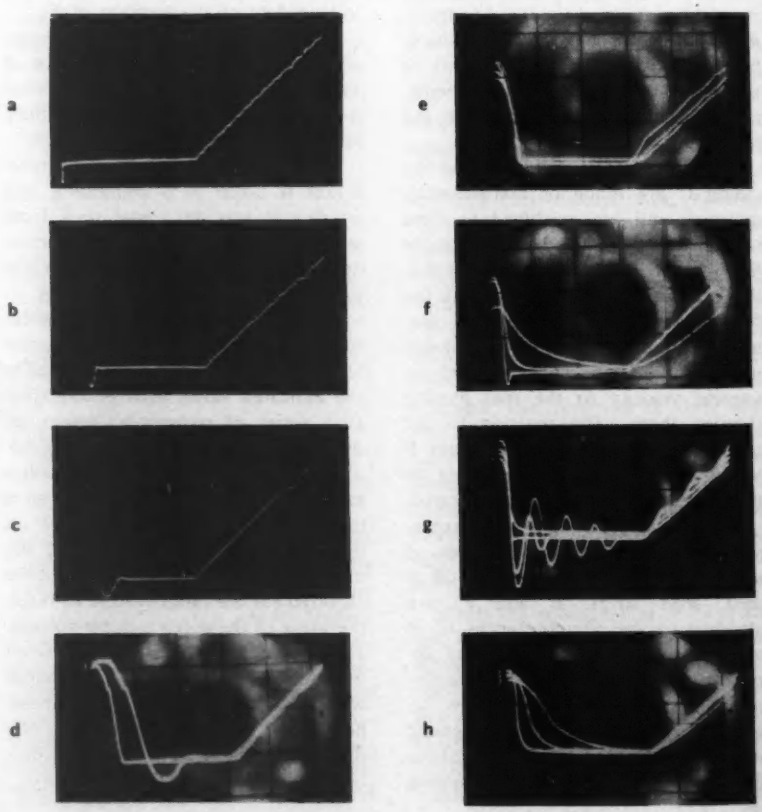


Fig. 3.2a Sweep speed 1 sec/cm (actual length of time-base approximately 5 cm). Servo damping critical

Fig. 3.2b As 3.2a, but sweep speed 400 ms/cm

Fig. 3.2c As 3.2a, but sweep speed 100 ms/cm

Fig. 3.2d Sweep speed 100 ms/cm, showing the effect of increasing the inertia of the mechanical load on the output by a factor of 3

Fig. 3.2e Sweep speed of 100 ms/cm using 0·05 μF across 1 MΩ output rate damping, and showing the effect of 0, 0·05 and 0·1 μF input rate damping across 1 MΩ

Fig. 3.2f Sweep speed 400 ms/cm, showing the effect of altering the gear-ratio from 16 : 1 to 64 : 1 and 256 : 1

Fig. 3.2g Sweep speed 400 ms/cm, showing the effect of 0, 0·01, 0·05, 0·1 and 0·25 μF output rate damping across 1 MΩ

Fig. 3.2h Servo heavily overdamped, showing the effects of increasing the ramp speed from 12·5 V/sec to 24 V/sec and 48 V/sec. Sweep speeds 400 ms/cm, 200 ms/cm and 100 ms/cm respectively

Loop control in Italian rod mill

Photo-electric loop regulation gives a high-quality product in spite of high rod speeds

A WIRE-ROD MILL WHICH WENT INTO service last year at the Aosta works of an Italian steel firm, Nazionale Cogne Società per Azioni, is now producing rods of quality steel for wire rope, ball-bearings, springs, tools and so forth. The tolerances and surface finish of the rolled rod are of a high order and this means that the rod must never be stretched between stands. In order to avoid this, loops are formed between one stand and the next. Furthermore, one rod only can be rolled at a time and, therefore, in order to give a satisfactory rate of production, fast outgoing rod speeds are used. However, the loops between stands must be fairly short in order to obviate cooling, which would create a difference in temperature between the ends of the rod.

This problem of loop regulation has been overcome with the aid of photo-electric equipment by the Swedish firm A.S.E.A., which company (or its licensees in Italy) provided the greater part of the electrical equipment for the Aosta wire-rod mill. A general view of the mill appears in Fig. 1. It consists of a three-stand roughing mill, an intermediate mill of three two-high stands, a four-stand looping mill, and a continuous rod mill consisting of three vertical and three horizontal stands.

In the last stand of the continuous mill, the rod speed is more than 4000 ft/min and as the loop formed to obviate stretching must not be so long as to lead to excessive cooling, the loop length is regulated to an accuracy of ± 4 in. by accurate motor-speed control. It is understood that a speed error of 1% at this position would reduce the loop from its normal length of 16 in. to zero in less than two seconds, with consequent stretching of the rod.

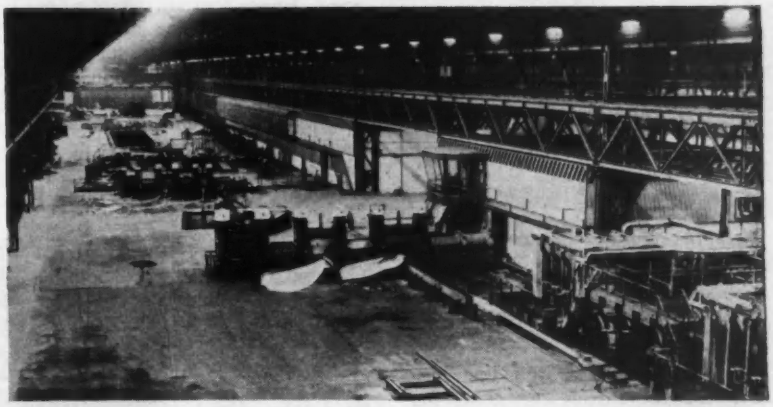


Fig. 1 The rolling mill comprises roughing, intermediate, looping and continuous mills

The A.S.E.A. loop regulator

Three of the four motors of the looping mill and all six motors of the continuous mill, are fitted with loop regulation equipment. This receives control signals from a photo-electric position transmitter which, in fact, measures the angular co-ordinate of the boundary between a hot object—the loop—and its cold background. The principle will be apparent from Fig. 2. A rotating mirror is driven by a synchronous motor fed at the supply frequency. This mirror reflects the radiation from the hot loop on to a photocell sensitive to infra-red rays, the latter emitting impulses having a phase-position dependent on the angle of incidence of the incoming radiation. These impulses are amplified and transmitted as ignition impulses to a thyratron regulator, the anode voltage of which is in phase with the voltage supplied to the synchronous motor. The output voltage of the thyratron regulator is thus dependent on the position of the loop, and is used as a signal in the control circuit for the speed regulation of the rolling-mill motors.

Regulation at Aosta

A simplified diagram of the loop-regulation arrangement for the continuous and looping mills at Aosta works is shown in Fig. 3. The speeds of the individual driving motors are controlled by regulating their fields. The field winding of the motor is connected, in series with a booster exciter, to a constant direct voltage, and variations in the field current are made by changing the excitation, and hence the output voltage, of the booster exciter. The latter is controlled by a push-pull-connected magnetic amplifier, the output voltage of which is determined by the current level in the control winding. In the steady-state condition, the tachometer-generator voltage is opposed and equal to the reference voltage, resulting in zero control current.

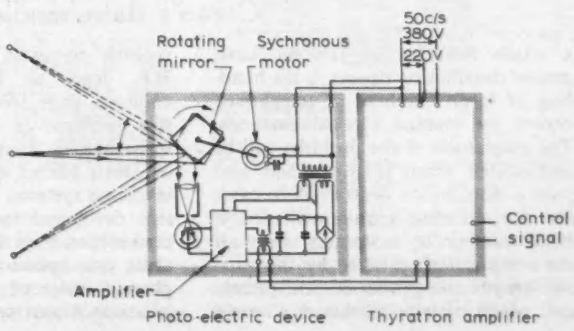


Fig. 2 The A.S.E.A. photo-electric loop-regulator. A rotating mirror driven by a synchronous motor reflects radiation from the loop on to a photocell, which thus provides a signal proportional to loop position

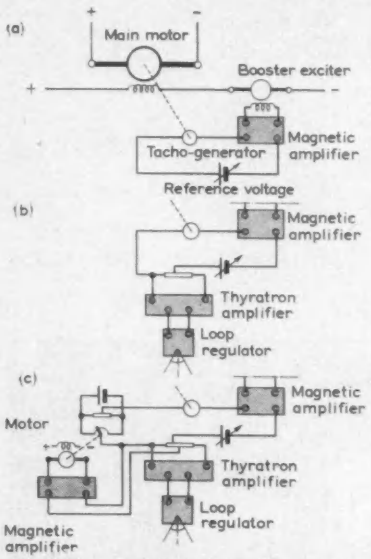


Fig. 3 The regulation circuit: (a) motor-speed regulation by field control; (b) loop regulation is provided by feeding loop-position signals into the speed-control circuit; (c) loop regulation corrected for temperature and roll-wear

If motor speed falls, while the reference voltage remains the same, the equilibrium in the control circuit is disturbed and a control current is obtained which affects the magnetic amplifier and consequently the booster exciter in such a way that the motor field current is reduced, whereupon motor speed increases and equilibrium is restored. The motor speed (which can be selected by varying the reference voltage) is thus held virtually constant irrespective of variations in the load.

However, the ratio between the outgoing speed of the rod from a stand and the peripheral speed of the rolls is not constant, but varies with the temperature of the rod. The movement of the loop between two stands indicates how the individual speeds of the stands correspond to each other. By measuring the loop position, and by introducing the measured value into the control circuit, speed regulation is obtained which takes these variations into consideration. In fact the photocell arrangement already described, senses the position of the hot loop and provides an output proportional to loop deviation. This signal is amplified and introduced into the control circuit.

Only three motors in the looping mill are fitted with loop-regulation equipment, the speed of the fourth stand being constant. Regulation is 'forwards' in the continuous rod mill and 'backwards' in the looping mill, so that the loop regulator in the continuous mill controls the speed of the following stand, and, in the looping mill, the speed of the preceding stand. In the continuous mill, greater demands are made on regulation than in the looping mill. For this reason the rod mill's loop-regulation equipment is supplemented by a device which automatically corrects the loop position for temperature variations, roll wear, etc. This device appears at the bottom of Fig. 3. The loop is correctly positioned when the voltage from the loop regulator is zero. While this voltage regulates the motor speed extremely rapidly, it also (via a magnetic amplifier and a slow-running motor arrangement) resets the reference voltage for the basic speed as soon as the voltage from the loop indicator begins to deviate from zero.

This means that the mill will automatically operate at the correct motor speed even if that speed has been incorrectly set. When changing the rolling programme, the speed is set so that the rod is stretched between the stands. The loop-regulation arrangement then takes over and adjusts the motor speed so that all loops are of the correct length.

Reliability

According to A.S.E.A. the relative complication of the regulation equipment at the Aosta mill has not led to any reduction in operational serviceability, and highly-qualified service personnel are not necessary. They suggest that this is due to the extensive use of magnetic amplifiers rather than electronic valve systems.

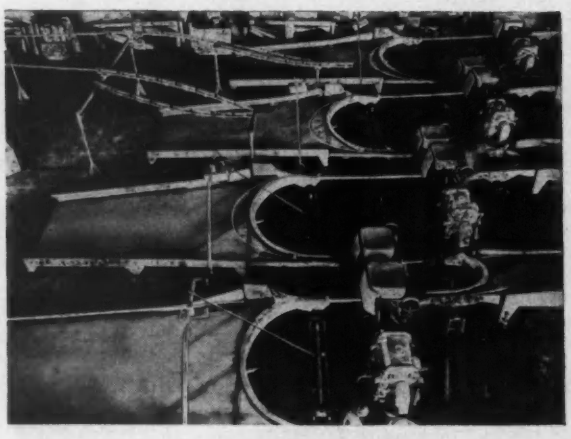


Fig. 4 Three of the eight loops in the looping mill are electrically regulated

CONTROL IN ACTION

Order mechanization at Shell-Mex and B.P.

Creed's data-handler, Doris, speeds clerical procedure at Royston

A MAJOR PROBLEM AT THE OIL COMpanies' distribution depots, is the handling of large numbers of telephoned orders by manual clerical methods. The magnitude of the problem will be appreciated when it is realized that such a distribution centre has to cater for the differing requirements of a large number of customers, with all the complication entailed by the various brands and grades of oils, petrols etc., which may be marketed. *Control* recently re-visited the Shell-Mex and B.P. depot at Royston (see these columns, page 169, May 1960), where this problem is being tackled with some success. There we saw a trial run of Doris (direct order recording and invoicing system), a data-handling system developed by Creed and Co. in conjunction with Shell-Mex, which enables one operator to handle a telephoned order of average complexity in about fifteen seconds.

The input console at which the operator sits is shown in Fig. 1. This has 3000 push-buttons carrying customers' names in alphabetical order. (About 1300 are in use at Royston.) A central panel carries push-buttons covering product, quantity required, delivery date, method of delivery, packing, and certain special instructions.

As an order is received by telephone, the operator presses the ap-

Fig. 1 (left) Doris's input console

Fig. 2 (below) Schematic diagram of order - processing equipment

propriate customer-button and then sets up details of the order on the central panel. In the event of any vital information being forgotten (e.g. date of delivery), a warning light appears over that particular section. A 'transaction' button clears each item, and an 'end of order' button clears the console. All this information is punched in code on to an order record (input) tape, with the exception of quantity which is punched directly in gallons.

Searching the tape stores

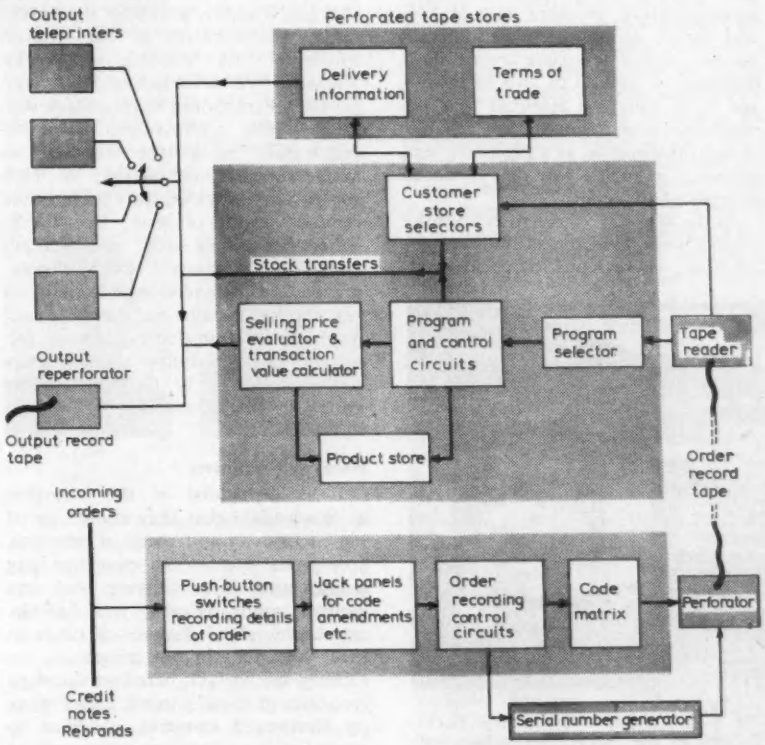
The input tape passes automatically to a tape-reader, and its various codes instigate a search—this takes about 10 sec—in three tape-stores. These are: 'delivery information store', which contains delivery address, invoicing address if different from the former), standard special instructions affecting delivery, customer's punched-card number, an area code, and the sales representative's code; 'terms of trade store', which contains the particular trading information applicable to the product groups taken by each customer; and 'product store', which contains full details of all products which are likely to be ordered.

On reference to Fig. 2 it will be seen that the information from these stores, plus that on the input tape, is fed to the program and control circuits, where it is put into sequence to feed the output printers and reperforator.

Pricing

As information is fed to these output mechanisms, the zone price for a particular brand is fed to the 'selling price evaluator' together with relevant rebate information from the terms of trade store. The evaluator is an arithmetic unit, which calculates the extended value of each transaction, and adds the cost of all transactions on each order to give a final invoice total.

In this manner, the output printers and perforator obtain all the information required to print a delivery



note and invoices. The output perforator produces a tape carrying the customer's name-code by punched-card and ledger numbers, all order details, and additional statistical information. This output tape, which is automatically over-printed with the order serial number to facilitate identification, is held in a tape rack pending the delivery of the order to the customer. When the tanker driver has delivered the order, he returns the delivery note, and the appropriate tape may then be removed from the rack and summarized.

Stock control and accounting

The output tape is fed to the summarizer-reader, the summarizer (see Fig. 3) then totalling the number of gallons of each type of fuel delivered, and the final value of all orders. At the end of each day, a summary is printed for each main product group, together with the total monetary value by credit and cash deliveries for local stock and cash control. A copy is also sent to divisional office for area stock-control. As each delivered order is summarized, the reperforating punch produces a tape perforated in punched-card notation for each transaction of each order. These tapes are transmitted to the divisional office for the information to be transferred on to punched cards for customer accounting.

Amending the stores

Periodically, information on one or more of the storage tapes will have to be amended. To do this, a copy of the original tape is itself automatically

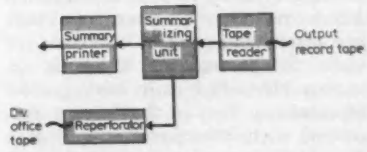


Fig. 3 Completed orders are summarized for stock control, etc.

copied, the copy-punch having an automatic counter which is pre-set to the code number identifying the customer whose details are to be altered. When this number is reached, the

machine stops and the operator switches the punch from automatic to keyboard operation, and inserts the new information manually. The punch is then allowed to run on until the next customer's code number, whose details require amendment, is reached, and so on until all alterations have been made.

Conclusion

Control was much impressed by this apparently successful mechanization of a complex clerical procedure. Although Doris is not yet fully operational at Royston, there is every reason to believe that the problems associated with handling telephoned orders at peak periods have been overcome. Equipment of this type may well become standard.

CONTROL IN ACTION

Instrumentation at Spadeadam

THE STATIC PERFORMANCE-TESTING OF rocket-propulsion units calls for extensive recording of such parameters as temperature, pressure, rate of flow and thrust at hundreds of different points. Typical test runs are of short duration—a minute of two at most—and it is therefore essential that the instrumentation should be reliable, obtain information at a high rate, and present it in such a way that it can be interpreted in detail.

At the Ministry of Aviation's Spadeadam, Cumberland, rocket-testing establishment, where Rolls-Royce are testing their l.r.b.m. (Bluestreak) engines, a complex system of instrumentation is being installed to extract the fullest information from each test run. There are several independent test pads for static firing, each of which is remotely controlled from underground blockhouses. Part of the control area of one such blockhouse is shown in Fig. 1. Firings are observed through the episcopic window in the wall at the right, while the submarine-type periscope in the roof can be lowered to give a close-up view of the pad. On the left are control desks, while behind them are some of the recorders which obtain the physical data on each test.

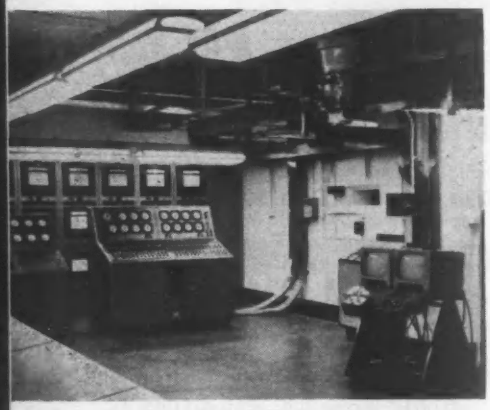


Fig. 1 Part of one of the control blockhouses at the Spadeadam rocket-test site. The pad is viewed through the episcope in the right wall, or by means of the periscope in the roof. Some control desks and recorders are visible at the left. Note Pye television monitors

The instrumentation was the responsibility of the Pye Group as subcontractors to a consortium, British Oxygen Wimpey, who built the Spadeadam establishment to the requirements of the Ministry of Works. Various Pye subsidiaries were concerned: Pamphonic Reproducers supplied public address and intercommunication equipment as well as acceleration-testing systems; W. Watson & Sons provided the episcopes for remote viewing of tests; Pye T.V.T. were responsible for closed-circuit television equipment; Pye Telecommunications provided mobile radio on site during installation; and probes, displacement transducers, cathode followers and resistance thermometers were supplied by W. G. Pye, Labgear and T.V. Manufacturing.

Honeywell recorders

It is demanded of the recorders at Spadeadam that they should be of high sensitivity and speed of response, free from interference over the long transmission lines between pad and control room, reliable and flexible, and enable rapid changes of range to meet variations in test criteria.

They are, in fact, based on standard recorders in the Electronik range made by Honeywell Controls, modified to cater for the special requirements of rocket-motor testing. These instruments are of the well-known self-balancing type in which accuracy is obtained by continuous voltage-balance, the incoming signal, proportional to the variable being measured, being balanced in a bridge circuit against a standard signal derived from a known voltage. Any unbalance in the two values, due to a change in the input, is amplified and used to drive a motor which moves a slidewire potentiometer to restore balance. The balancing movement is transmitted to the recording pen and pointer which, therefore, move by an amount proportional to the change in input. The process is carried out continuously to an accuracy of $\pm 0{\cdot}25\%$ in the 10 mV-range and to $\pm$ 0·3% in the 5 mV-range. Constant voltage units employ-in a Zener diode standardize the balancing voltage.

Since the duration of a test run is so short, the record must be complete from the first instant, and to ensure this a special inking system has been devised to overcome the possibility of sluggish pen operation after a period of rest. The pen itself is jewel-tipped, and the reservoir supplying it with ink is pressurized by an air supply. This arrangement is understood to ensure a good but controlled supply of ink right from the start of recording.

Another feature of these instruments is that the chart-speed can be altered quickly for different types of measurement. In normal industrial service, chart-speed is changed only rarely, and the standard arrangement of changing the drive pinions is perfectly acceptable. But as hundreds of recorders must be attended to, and perhaps reset for tests occurring in rapid succession, the pinions have been replaced by a gear-lever change system. To provide for the rapid interchange of instruments for a variety of tests involving different sensing heads, the recorders accept inputs over an impedance range from 0 to 5000 ohm.

The speed of response to transient signals is also important, and Honeywell claim that by reducing the weight of moving parts they have achieved a figure of 0·9 sec for full-scale deflection over the 11-in. chart.

The installation includes an alarm feature, covering the desired 'high' and 'low' limit values.

The blockhouses are some distance from the test pads and linked to them by cables carrying signals from the various sensing devices to the instruments. Special circuits have been built into the recorders to eliminate interference between the various channels, while the full sensitivity necessary to handle the small outputs of some of the elements (5 mV for full-scale deflection in some instances) is retained.

Although these recorders are based on standard instruments of the type used in oil refineries and other process industries, the demands of the job have resulted in 'specials' which are superior to the standard model in certain respects. *Control* understands that these modified instruments are now generally available.

PEOPLE IN CONTROL

by Staffman

Texas Instruments, along with the other semiconductor firms, appear to be girding their loins for the battle to come. I gather that there are now umpteen firms in the field, and it looks as if they can't all obtain more than their fair share of the market. Last month I reported Texas' reorganization which would make one department wholly responsible for a particular product, from development to sale. Now I learn that **C. P. Dotson,** Texas' Chairman 'has, with regret, accepted the resignation of **Dudley Saward** as Managing Director'. Saward, who remains a Director, intends devoting more time to his other activities. He is known to be interested in space research, but I expect to hear shortly of his accepting another senior appointment within the electronics world. The new M.D. at Texas is **A. N. Provost,** who held a number of senior posts in the U.S.A. before joining Texas Instruments Inc. in Dallas.

Also in the semiconductor world, **W. N. Richardson** has been appointed Marketing Manager of Hughes International (U.K.) Ltd. Richardson, who was Commercial Manager of Plessey's Towcester Division, and, before that, General Sales Manager of Salford Electrical Instruments, will initially be concerned with (U.S.) Hughes Aircraft's semiconductors, most of which are now in production at the Glenrothes, Fife, plant.

SAWARD
new job?

PARTOS
new factory

I was interested to learn that Dr **Paul Partos,** Manager of Honeywell Controls' Systems Division, is to head a new 30,000 ft² Honeywell factory at Hemel Hempstead. I gather that they hope to commence operations—the manufacture of data handling and computing systems, scanners and panels for complete industrial control schemes—early in 1961. Partos was, of course, with Elliotts for some years, being Chief Engineer of the Systems Division and Technical Manager and Chief Engineer of Panellit, prior to joining Honeywell last year.

LUPTON
contracting

RICHARDSON
marketing

Neville L. Lupton, who becomes Contracts Manager of Plessey's Electronics and Equipment Group, joined Sperry in 1941 after service with the R.A.F. Sperry seconded him to the U.S. 8th A.A.F. as an armament specialist, and he later founded and became chief instructor of the U.S. Power Turret School at Kirkham, Yorks. Lupton returned to Sperry in 1944, remaining there until joining Microcell in 1958. He was Microcell's Commercial Manager prior to joining Plessey.

American Machine and Foundry—A.M.F.—is establishing a laboratory near London, for research into chemistry, physics and electronics. This project is being directed by **Hamilton Herman,** Vice-President and Director of R. & D. for A.M.F., and organized by **J. Wilson** and Dr **A. D. Booth.** Wilson managed Triplex Safety Glass's Research Laboratory at one time, built up the British Rubber Producers' Research Association for the Colonial Office, and from 1947–57 built up the British Rayon Research Association under D.S.I.R. Booth should be well known to readers of *Control*—see, for example, his *The diverse nature of switching* (published last June), a discussion of an international symposium held at Harvard. An X-ray crystallographer at one time, he is probably best known for his work with computers—he is London University's Director of the Department of Numerical Automation.

A new tracing attachment for machine tools (the Mimik tracer—see *News Round-up*) was demonstrated in London recently by **Lincoln S. Magor,** president of the Canadian firm Retor Developments. Commenting on his company's origins, Magor explained that he originally formed Magor Aviation, to develop a novel v.t.o.l. aircraft. This project was eventually abandoned, the reason given—not entirely seriously I suspect—being that the cost of hiring computer time for checking calculations was found to exceed the estimated cost of producing a prototype aircraft. After linking with Barrett's Engines, and becoming Retor Developments, the company turned its attention to machine tools. The tracer has apparently already achieved considerable success in Canada and the U.S.A., and they are now attempting to enter the European market. Magor remarked that they were starting with the U.K., partly because they hoped the linguistic difficulties here might be less acute than elsewhere.

I hear from **P. B. Ades** of Airmec that he has been appointed Sales Director, and that a colleague, **B. J. S. Tetlow,** becomes Works Director. Both have been with Airmec since 1947, prior to which Ades was with Marconi Instruments, and Tetlow with Philco.

ADES

FRY
directing sales

Solartron's fifth employee—he joined the Group in early 1949—**Wilfred J. Fry,** a director of Solartron Research and Development, has been appointed Sales Director and Commercial Manager of Solartron-John Brown Automation. Last year Fry was responsible for forming Solartron's division concerned with analogue computation and industrial data processing. Now I suppose he will be mainly concerned with the exploitation of 'automated commodity dispensing systems' such as the Gompertz automatic warehouse for which the Solartron-C.J.B. company holds the world rights.

AUTHORS IN CONTROL

K. C. Garner (*Interkama in Düsseldorf*, page 84). See page 121, June 1960.

R. S. Medlock (*Progress through instrumentation*, page 86) joined George Kent Ltd as a research electro-chemist in 1935, on graduating from University College, London. In 1940 he was a control engineer, and six years later Research Manager, becoming Research and Development Manager in 1948. He became Technical Director of George Kent Ltd in 1956, Technical and Home Sales Director in 1958, and, more recently, Engineering and Research Director. A Member of the I.E.E. an A.R.I.C. and A.M.I.Mech.E., Medlock was President of the Society of Instrument Technology during 1959-60. He specializes in process control, electro-chemical measurements, and electronic measurement, and is *Control's* consultant on engineering and applications.

John Tindale (*Control mechanisms for nuclear reactors—A*, page 89) received early training as a prize engineer-pupil of Fraser and Chalmers Engineering Works Ltd, during which time he read mechanical sciences, electrical technology and power transmission, and land survey as an external undergraduate of London University. He was elected Graduate and Associate Member of the Institution of Mechanical Engineers in 1931 and a full Member in 1946. He joined Spencer (Melksham) Ltd as a designer of mechanical handling equipment and later Strachan and Henshaws of Bristol in a similar capacity. In 1929 he was

MEDLOCK

TINDALE

appointed Assistant Chief Development Engineer of the Avon India Rubber Works, leaving in 1931 to join Vickers-Armstrongs' Gun Fire Control Department. During the war he was loaned to the Admiralty at the request of the Director of Naval Ordnance. In 1946 he re-joined Vickers-Armstrongs to take up a new appointment in charge of the Research and Development Department at Crayford. In 1948 he was appointed Chief Engineer at the Research Laboratories of Elliott Brothers (London) Ltd. Later he became Manager of Elliott's Mechanical Engineering Division, and at present holds the position of Assistant Joint General Manager.

Peter Sutherby (*Computers for process automation*, page 93) graduated in mathematics from Peterhouse, Cambridge, in 1954 and joined Elliott Brothers in January 1957, after working for Bristol Aircraft Ltd on the performance and stability of helicopters. He started working on industrial digital-control systems in the Research Division at Borehamwood, and in 1958 joined the Systems Group at Lewisham. In 1959 he worked in the Analogue Simulation Service for a period and co-operated in early work on the Optimat process-control computer. He is now Head of the Systems Study Department of the newly-formed E. A. Automation Systems Ltd.

SUTHERBY

FINKELSTEIN

Ludwik Finkelstein (*The theory of invariance*, page 96) was educated at the Northern Polytechnic (University of London) where he read physics and graduated in 1959 with the degrees of B.Sc. (General) in pure mathematics, applied mathematics and physics and that of B.Sc. (Special) in physics. After a year on the technical staff of Electronic Tubes Ltd, he joined the Mining Research Establishment of the National Coal Board where he was concerned with the applications of instrumentation in mining. In December 1959, Finkelstein was appointed Lecturer in Measurement and Automatic Control at the Northampton College of Advanced Technology, London. An A.Inst.P., he took his M.Sc., at the Chelsea College of Science and Technology, by part-time study, with a dissertation on *Magnetostrictive transducers*.

A. J. Morton (*Boiler feed discharge systems under changing load*, page 99) graduated from Manchester University with first class honours in mechanical engineering, and entered the R.N.V.R. in 1944, serving as a watchkeeping engineer officer in the British Pacific Fleet. In 1947 he joined the Parsons Marine Steam Turbine Co. Ltd, and later became a lecturer in engineering at the University College of Swansea. He was awarded the degree of M.Sc. (Manchester) in 1959 for a thesis on turbine critical speeds. From 1952-58 he worked on full-scale naval boiler and turbine trials at Pametrada (where the work on

MORTON

which his present article is based was carried out), and then joined the project staff of the Hawker Siddeley Nuclear Power Co. Ltd. He took up his present appointment as Head of the Mechanical Engineering Section in the Power Generation Branch of the C.E.G.B. Research and Development Department in 1959.

P. F. Blackman (*Pole-zero approach to system analysis*—1, page 102) graduated from University College, London, in 1951, and was a postgraduate student at Imperial College until 1955. He was then appointed lecturer in the Control Section of The Department of Electrical Engineering at Imperial College. During 1957-58 Blackman spent a year in the Department of Mechanical Engineering at the Massachusetts Institute of Technology.

J. J. Foody (*Controlling v.t.o.l. aircraft at transition speeds*—3, page 107). See page 125, September 1960.

J. R. Spencer (*Miniature recorders*, page 112) was with Muirhead and Co. Ltd, initially in the Instrument Wiring Shop and then in their Test Room. Whilst there, he attended part-time day courses at The Northampton Polytechnic, obtaining a H.N.C. in electrical engineering in 1951. Later that year he took up an appointment with The British Iron and Steel Research Association, working on instrument development, mainly in connexion with automatic control, although it did include some time in a team doing more fundamental work under the consultancy of Prof. E. N. da C. Andrade, F.R.S. In 1954 he entered University College, London, to read mathematics and physics and, after graduation, was employed as an instrument design engineer in the Chief Engineer's department of British Nylon Spinners at Pontypool. Spencer then joined his present employers, The British Petroleum Co. Ltd, initially at the Sunbury Research Laboratories, and later being transferred to the Control Engineering and Instrumentation Group at B.P.'s Head Office. He was responsible for laying down the specification for Ceres — control engineering research electronic simulator.

NEWS ROUND-UP

from the world of control

B.C.A.C.

Conference reform

In *Control's* leader last September the hope was expressed that the British Conference on Automation and Computation would be 'reborn and magnified' after the London symposium on the recent Ifac Congress (the symposium was reported in last month's *News Round-up*). Readers will hear with mixed feelings that the hope has been fulfilled—mixed feelings because the new babe may not be lusty enough nor the magnification great enough.

It was agreed on October 10, at a meeting of the B.C.A.C.'s three groups, that the Conference would operate more effectively under a central council. The groups have now merged, adopting as their objects:—

a To stimulate interest in, to spread knowledge of, and to foster the development and applications of automatic control and computation

b To afford a common meeting ground for the adhering organizations whereby such of their activities as fall within the purview of the Conference can, if they so desire, be co-ordinated and extended

c To encourage and, if desired, to co-ordinate the presentation at international conferences of British papers whose subjects fall within the purview of the Conference

d To maintain, as may be desirable, liaison with other countries which support such international conferences.

Detailed proposals will be considered shortly by the executive committee in which, under the new constitution, the B.C.A.C.'s management is vested. Chairman of the Conference is Sir Walter Puckey, with Messrs L. T. Blakeman, J. F. Coales and H. G. Conway as Vice-chairmen. Mr. W. K. Brasher (Secretary of the I.E.E.) is the Hon. Secretary, and the I.E.E. will provide secretarial service. On the executive committee with the honorary officers will be: Dr E. H. Bateman (Structural Engineers), Mr W. J. Carron (T.U.C.), Mr E. C. Clear Hill (B.C.S.), Mr W. C. F. Hessenberg (Iron & Steel Institute), Prof. G. D. S. MacLellan (I.Mech.E.), Prof. P. B. Morice (Civil Engineers), Sir Charles Norris (British Productivity Council), Prof. E. J. Richards (R.Ae.S.), Mr E. S. Sellers (I.Chem.E.), and a representative of the British Institute of Management.

The following organizations have transferred their allegiance to the new Conference: Association of Certified & Corporate Accountants; British Computer Society Ltd; British Institute of Management; British Productivity Council; Chartered Institute of Secretaries; Institutes of Cost and Works Accountants, Fuel, Marine Engineers, Materials Handling, Metals, Personnel Management, Petroleum, Physics and Physical Society, Welding; Institutions of Chemical Engineers, Civil Engineers, Electrical Engineers, Engineering Inspection, Gas Engineers, Mechanical Engineers, Mining Engineers, Municipal Engineers, Plant Engineers, Production Engineers, Structural Engineers, Water Engineers; Iron & Steel Institute; Royal Aeronautical Society; Society of Instrument Technology; Tavistock Institute of Human Relations; Trades Union Congress. The Department of Scientific & Industrial Research is listed as an 'Observer'.

AIRCRAFT

Telemetry consortium

A major air-to-ground multi-channel telemetry system developed by Elliott Brothers, McMichael Radio, Rank Cintel, Southern Instruments and W.S. Electronics, in conjunction with R.A.E., Farnborough, is to be exploited at home and overseas by a consortium of the five firms. W.S. Electronics acts on behalf of the consortium, which has been formed on the recommendation of the Ministry of Aviation.

C.J.B. control E.E. tunnel

The integrated control and operating system for English Electric's Mach 6 blow-down type wind tunnel at Warton Aerodrome, Lancs., was installed by the Automatic Control Division of Constructors John Brown. The wind tunnel, which will be used for g.w. research, is designed to run for intermittent short periods at airspeeds up to 4500 mile/h and operating speeds of the control system are fairly high. The control system is used to set up a wide range of operating conditions quickly and safely with self-checking facilities, and also provides for fully-automatic or manual operation of the tunnel. Extensive interlocking, inherently safe circuits and the use of fast-acting emergency systems, are said to prevent dangerous conditions.

In general, the operating systems are of the high-pressure, oil-hydraulic type, the control circuits being electro-mechanical and electrical, a number being designed for precise positioning. The wind tunnel is controlled from a central console and separate local panels are provided for setting-up and checking the various sections of the tunnel.

Trident control

Experience of carrying out automatic aircraft landing in thick fog suggests that basic monitoring dis-

The D.H. Trident's flight control system. The instrument system layout (top) bears a natural relationship to the controller (bottom)

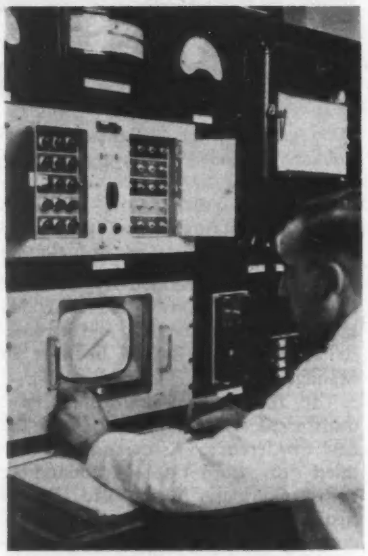
plays should be clear and simple, according to A. M. A. Majendie of Smiths Aviation Division in a paper *Aspects of instrument development for all-weather operation*, presented before the Guild of Air Pilots and Air Navigators, last month. Warning indications must be bold and unambiguous, and emergency controls and disconnect devices, obvious, positive and natural. The instrument system layout (illustrated) for the D.H. Trident jet airliner is intended to meet these demands. The central controller (also shown) for the complete flight control system, has a similar layout to the instrument display, giving a natural relationship between the two. The controller provides all controls including flight director functions, full manometrics (including twin air-data computers), an automatic throttle control system, all normal autopilot functions including dampers, full automatic landing and automatic overshoot for emergency use. Majendie said that the controller's design had provided Smiths with one of the most difficult tasks they had ever faced. Despite its relatively simple appearance, it provides over 3000 different combinations of switch-position—no mean task for the systems analyst.

I.E.E.-R.Ae.S. forum

A joint forum of the Institution of Electrical Engineers and the Royal Aeronautical Society has been formed to enable engineers in electrical engineering and aircraft construction to meet to discuss problems and new ideas affecting their common interest in aircraft electrical engineering. A Joint Committee has been set up under the chairmanship of Professor G. A. Whitfield of the College of Aeronautics, Cranfield.

Av. elec. and industry

The recent Brit.I.R.E. Convention on Aviation Electronics and its Industrial Applications, disappointed in that it did not really cover the intended theme—i.e. that work in aircraft electronics could be applied to problems in general industry. The papers were of some technical interest, however, although only *System engineering in theory and practice* by M. James and G. S. Evans of de Havilland, appeared to stick to the point. A great deal of interest was aroused by *Symmetrical transistors as a.c. or d.c. switches and their applications in modulator and demodulator circuits* by J. Evans, D. A. Gill and B. R. Moffit of Smiths. The problems of choppers, or transistor switches, are, of course, much in the news at the moment.



GAS TELEVISION The Northern Gas Board's new Sunderland gas works employs Pye closed-circuit television equipment for the remote viewing of instrument readings. Five cameras, positioned throughout the works, transmit instrument information to a central control room. The operator can view pictures from any of the cameras, and direct a particular camera on to any instrument within its range of view

EXHIBITIONS

Big three still independent

The second Interkama—International Congress and Exhibition for Instrumentation and Automation—which completed its eight-day run in Düsseldorf on October 26 (see K. C. Garner's *Interkama in Düsseldorf*, page 84), appears to have been a great success, at least, so far as the exhibition was concerned—the congress was marred by a lack of pre-prints, and too little discussion. According to the organizers, the exhibition was attended by 110,000 visitors, 35% of whom came from outside Germany.

Interkama is, of course, one of the three great international control and instrumentation shows of western Europe. Our own I.E.A.—Instruments, Electronics and Automation Exhibition—occurred last May and, being a biennial event, should take place again in May 1962. The comparable French exhibition, Mesucora—International Exhibition of Measurement, Control, Regulation and Automation—takes place from May 9–17, 1961. These three international exhibitions must obviously overlap to a great extent, although it is hard to say whether this is necessarily a bad thing or not. It is rumoured, however, that the Interkama authorities approached I.E.A. visitors to the Düsseldorf show, and suggested that each of the three exhibitions should be held at three-yearly intervals on dates arranged so that they would not overlap. The I.E.A. people are supposed to have replied that they would inform their committee of this suggestion, but held out very little hope of its acceptance.

Presumably the I.E.A. feels strong enough to compete at the international level with its continental rivals, and, therefore, sees no reason to reduce its exhibitions from one every two years to one in every three. There is also another possible reason for the I.E.A.'s apparent preference for competition rather than alliance. The I.A.E.'s organizers are also responsible for the Radio and Electronic Component Show (May 30–June 2, 1961). These two affairs are held in alternate years, and the many firms who show their products at both exhibitions are able to look upon them as a single event. In other words, far from being willing for the I.E.A. to take place triennially, certain British firms appear to want an international instrumentation and control show to be held in London every year.

A large market for control

Last month, *Control* visited the first Effluent and Water Treatment Exhibition and Conference, which was designed to bring together firms with effluent problems, local authorities, and manufacturers of treatment plant. The large attendance indicated a growing interest in this controversial (and sometimes litigious) subject. Exhibits of control-engineering interest included pH recorder-controllers, flowmeters, pressure and level indicators, etc. It would appear that there is a large potential market for systems for the automatic control and instrumentation of effluent disposal.

METALS

Bisra's Buxton conference

Last month's Bisra conference on automation in the iron and steel industry is understood to have been successful. It was, however, a 'closed' conference so the press did not attend, and *Control* has no direct knowledge of the manner in which the would-be industrial user of automatic control techniques received Bisra's somewhat advanced ideas on the subject. To write of Bisra's ideas as 'advanced' is not meant to suggest that they are of the blue-sky variety, but rather that the industry with which Bisra is concerned may not be quite as farsighted as its research association. The British

iron and steel world has achieved a tremendous amount since the war, but is enough known of the brutal art by which steel is produced to enable its proper instrumentation, let alone its production under computer control?

This aspect was touched on by Lord Halsbury, who delivered the opening address. He emphasized that the first step toward automation in any industry was the collection of operating data by means of full plant instrumentation. Only after complete operating data were available could the necessary operating rules be calculated for use with on-line computers in the automatic control of processes.

Mr S. S. Carlisle, an Assistant Director of Bisra, followed this opening address with an introductory review of automation in the iron and steel industry. He discussed sectors in which he felt the technology was already available to apply more automation—hot and cold strip mills, primary and plate mills and forging presses—and considered that there was virtually complete instrumentation of blast- and open-hearth furnaces. However, the case for further automation had to be properly evaluated, and it was necessary to learn more about the fundamental logic and technology of processes.

After a paper by Mr R. C. Gardner of The Reed Paper Group on automation in the paper industry, there was a general discussion and a ' brains trust '. Not having been there, *Control* is unable to gauge the attitude of the conference towards such probable questions as, is it worth while, how much will it cost, can it be done, can we afford it? Such questions as these will doubtless be speedily resolved once our foreign competitors have installed auto-control but, until then, finance, scepticism and apathy will probably prevent the British steel industry from paying very much more than lip service to closed-loop control.

MOTOR CARS

Crowthorne Research Track

The new road research track of the Road Research Laboratory was visited by *Control* late last month, and although nothing astonishingly new was to be seen, it was encouraging to find that this country is beginning to show some practical awareness of a subject which has received considerable attention abroad. Built at a cost of about £0·5m, the new track will be used mainly for research on traffic and safety measures, with particular emphasis on the behaviour of the driver-vehicle combination. Means are provided for experiments on guidance and control of vehicles in fog. A wire laid below the surface of the road is the basis of the guidance system, vehicle deviations from the line of the wire being shown by an indicator in the car.

The Laboratory is investigating ways of improving traffic flow on crowded roads by detecting congestion and trying to reduce it. Methods include diversion from congested sections by variable direction signs, control of inflow to roundabouts, adjustment of traffic signals to minimize queueing, and data transmission to police. The types of vehicle-presence detector which are being developed, work whether or not the vehicle is moving, in contrast with existing instruments. One consists of a loop of wire in the road surface, which can be used to detect metal within it, and the other depends on the Hall effect. A prototype traffic-density meter was shown which averages the output from a vehicle-presence detector to give the average density of traffic (in vehicles/mile) over a short time. This is weighted to give greater prominence to the most recent traffic, and can be used to operate a control device when the average density is excessive. One kind of control device would be a computer calculating quickest routes between any pair of points in a road network.

EXPORTS

The road to the buyer

Elliott Brothers have adopted the new approach to export selling; that is, taking their equipment by road to the foreign would-be user, and demonstrating it on the the spot. Because it is transistorized and, therefore, small and robust, the Elliott 803 digital computer can be transported in a 30-cwt van. This has enabled them to deliver the machine to, and successfully demonstrate it in, places as far afield as Moscow and Zurich, Brno and Paris. At a recent Press conference, *Control* was impressed to see the various units of the machine unloaded from the van, assembled, and a test-program run through, in under an hour.

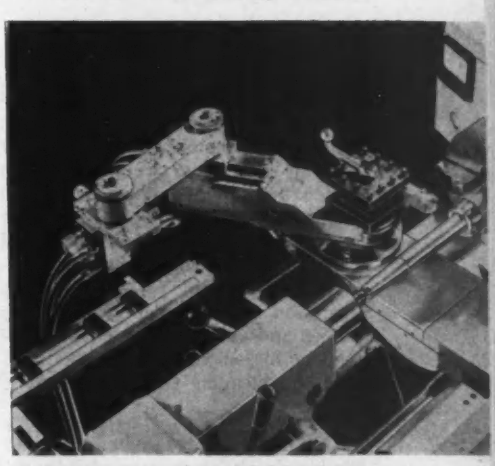
The normal procedure is for the export sales department to arrange a demonstration in the country concerned, and the van, manned by a driver and co-driver alone, sets off. An installation engineer joins the road team at the site, and the computer is set-up and prepared for action. A small sales team then arrives by air, the 803 is demonstrated, and the van—usually empty—returns to this country. During the recent Press demonstration we were entertained by stories from the sales team of their difficuties in transporting a computer within the U.S.S.R., and of the seemingly deliberate lack of co-operation. However, at the recent S.I.M.A. Exhibition in Moscow, for instance, the Russians showed tremendous interest in British equipment, particularly in its reliability and high quality, and A. G. Kennedy, who is export manager of Elliott's Computing Division said: ' Certainly as far as computers are concerned, these people know what they're talking about '. This must be gratifying to Elliotts for they sold the 803 which they demonstrated in Moscow.

Of the forty 803s ordered in the last year, 24 have been for export; fourteen have already gone abroad to Czechoslovakia, Finland, France, Germany, Russia and the U.S.A. This month the van is off to Poland.

MACHINE TOOLS

Transatlantic tracer

A Canadian firm, Retor Developments which was formed in 1953 to manufacture and market the ' Mimik ' tracing attachment for machine tools, is now attempting to break into the U.K. and European market with this device. Undeterred by the prejudice which has grown up in the industry against anything described as an 'attachment', Retor claims to have made good headway in Canada and the U.S.A. Many profiles, it is claimed, can be cut more rapidly with this system than by the more expensive numerical-coordinate methods—even allowing for the time required to make the template.



Here fitted to a Barber-Colman 1610 lathe, the Mimik tracing attachment may also be fitted to shapers, planers and milling machines

The sensing device on the tracer is a sealed hydraulic spool-type valve, which responds to a 6 oz pressure on the stylus round the full 360° of arc. The sensitivity of this valve enables

the tracer to work from templates cut from 0·003 in steel-shim sandwiched between plastic sheets. The use of this type of template—which is cut on a vertical mill with another attachment also supplied by Retor—saves a great deal of time compared with conventional methods requiring heavy gauge templates. This economy in template cutting time is said to make the Mimik system particularly suitable for short production runs.

FOOD

Auto-controlled ice cream

The Boston, U.S.A., ice cream plant of H. P. Hood & Sons is understood to be fully-automated, following the installation of equipment by Minneapolis-Honeywell Regulator. In addition to the computer-calculation of ice-cream mix formulae, an automatic mix system provides batch-blending of all ingredients by punched cards; graphic representation and centralized control of the entire mix process, including pasteurization, homogenization and cooling; automatic pasteurization; and both automatic and manual operation of the 'clean-in-place' system.

The integration of the system with new equipment is understood to have enabled Hoods to increase their production capacity by 70 per cent.

Punched-card control

An analogue computer determines how much of each ingredient is required for a given formula, and converts this information into (digital) pounds on a punched card. The latter controls electronic equipment that directs the flow of raw products from storage to the blending tanks. The card is inserted into an instrumented console, an electrical contact providing on-off control for the batching operation. Other contacts control the pumps and valves associated with unloading ingredient-storage tanks, and load two blending tanks alternately.

Flow measurement

The movement of ingredients into the blending tanks is measured by rotary flowmeters which generate pulse trains directly proportional to the quantity of liquid passing through them. The pulse trains drive totalizers, recorders, etc., in the control room. When a flowmeter signals that the quantity punched on the formula card for a particular ingredient has been reached, the pump and valves for that product are de-energized, and this process continues until batching is complete.

All dairy ingredients are batched simultaneously into a common line to one of two 1000-gallon blending

The ice-cream mix at Hood's, Boston, U.S.A., plant is punched-card controlled

tanks. Other ingredients, including liquid sugar and chocolate, are automatically metered into this line. The blending tanks are equipped with 'high' and 'low' level probes, so that if a tank becomes full the high-level probe shuts off pumps from the product tanks and sounds an alarm.

Nine 2000-gallon ingredient-storage tanks are also equipped with high-and low-level probes. In the event of low level during batching, an alarm sounds, and a light on the graphic console indicates the tank involved. The operator then either switches to another storage tank, or waits until the batching cycle is complete before inserting a special punched card in the batch-blending console to make up the missing ingredient.

Honeywell Scotland doubles

The British subsidiary of Minneapolis-Honeywell Regulator, Honeywell Controls Ltd., will nearly double the size of its Lanarkshire factory over the next three years. The factory, which is on the Newhouse Industrial Estate at Motherwell, now covers 190,000 ft², and is to increase in size to 350,000 ft². The present labour force is 2000, and the extension is expected to provide employment for 1000 more people.

BUSINESS

Pye-Ekco merger

Last month the English Electric-General Electric Co. discussions on the possibility of a merger were reported in these columns, and now we learn that Pye and E. K. Cole plan to merge. It appears that the idea is to form a £25–30 m group under a holding company. Pye's chairman, C. O. Stanley, will be chairman, and Eric Cole, chairman of E. K. Cole, deputy chairman. First thoughts suggest that the problems of the domestic market—i.e. television receivers etc. — have prompted this latest merger, but it is not unlikely that the costs of research for the professional or capital-goods market have something to do with it. Presumably the future lies with electronics and instrumentation, rather than in the very competitive consumer radio field. It has also been suggested that the high costs of export sales in terms of sales staff, tend to make exporting an expensive procedure. Obviously if a single sales force handles the products of both concerns, there will be a large saving.

IN BRIEF

British Standard B.S. 1991, *Letter symbols, signs and abbreviations.* Part 1: General is to be revised. However, as four further parts (Part 2: Chemical engineering, nuclear science and applied chemistry; Part 3: Fluid mechanics; Part 4: Structures, materials and soil mechanics; Part 5: Heat engines) are to be issued early in 1961, it has been decided to issue an amendment (PD 3920) to Part 1, which modifies the standard to avoid inconsistencies between the parts.

Vactric (Control Equipment) Ltd have stated 'No doubt you will have observed . . . the difficulties which have overtaken Vactric Ltd. . . . Vactric (Control Equipment) Ltd. is a completely separate company from Vactric Ltd. . . . This Company [Vactric (Control Equipment) Ltd] will proceed as usual and continue to execute existing contracts without any interruption whatsoever.'

Productivity will be the main theme of the Ninth S.I.M.A. Convention at Eastbourne, 17-20 November.

Plessey are negotiating for the old 66-acre R.A.F. Balloon Barrage Station, Southampton, and, subject to planning permission, hope to start producing components there before the end of 1961.

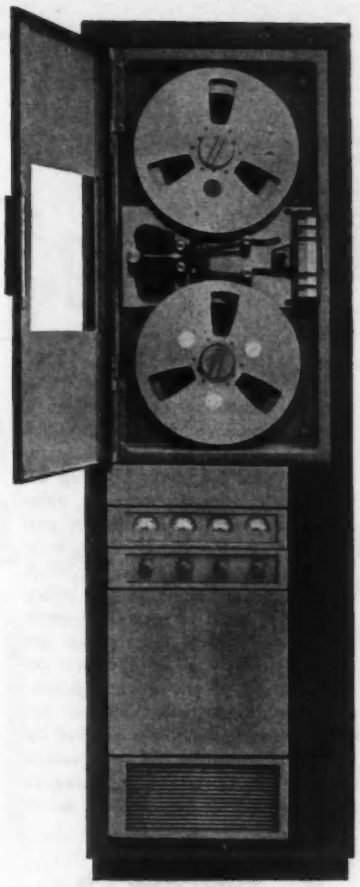
Associated Transistors Ltd (A.T. & E., English Electric and Ericsson Telephones) expect to produce 15,000,000 transistors a year by 1963 in a £850,000, 120,000-ft² plant which is being constructed at Basingstoke.

New Electronic Products—galvanometer recorders, digital magnetic-tape recorders, the Melrose heart and lung machine, etc.—have been acquired by Honeywell Controls Ltd. N.E.P. will operate separately under its Managing Director, Z. F. Kellerman.

Elliott Brothers' Rochester works will be able to employ more than double the present 2000 people, when their 450,000 ft² electronics factory (on which work started last month) is complete.

Satellite communications: an official team of British communications experts is now in the U.S.A. for technical discussions on communications via earth satellites.

G.E.C. Semiconductor Division have acquired Broadstone Works, Reddish—600,000 ft² of production space for semiconductor manufacture.



The AMPEX FR-100B is a high performance instrumentation magnetic tape recorder suitable for a wide variety of industrial and scientific applications. In manufacturing it is used extensively in both machine tool and process programming. In research it will record such diverse things as the thrust measurements of a jet engine, cosmic ray counts from a satellite, or vibration data developed in testing a new car body. This information can be recorded by direct techniques, on an FM carrier, by pulse duration modulation, or through NRZ digital techniques. It is capable of recording up to 14 analogue or 16 digital tracks, operates at any of 6 standard speeds from 1⅞ to 60 inches per second... can be modified for other speed combinations. And, depending on the system used, it will record from a direct current signal up to 100 kilocycles, ±3 db. The FR-100B will also reproduce tapes it has recorded, or those made on similar Ampex machines. I.R.I.G. compatible at no extra cost. For complete information on this remarkable recorder write to Ampex Great Britain Limited, Arkwright Road, Reading, Berks., England. AMPEX

Pick-off

by 'UNCONTROLLED'

LORD HAILSHAM RANG his bell for the classical scholar a few weeks ago when he opened a D.S.I.R. conference on industrial ergonomics. He advanced a number of witty arguments to show that the classical scholar still has plenty to say to the scientist, and went on to defend the respectability of *ergonomics*—at least as a word. 'It is derived, of course, from the Greek *ergon*, work, which gives it a respectable character to begin with, and *nomos*, law, and *ics* is simply a rearrangement of the first initial letters of the Council of Industrial and Scientific Research! The Medical Research Council, which is equally responsible for ergonomics, is not allowed to advertise except on its door-plate, and so it does not occur in the name'. Both of those councils are in Hailsham's parish as Minister for Science. Certainly there has been a good deal of official pushing of ergonomics lately, and with some success. The D.S.I.R.'s three-day conference drew about 300 people from nearly 200 firms and other organizations. And the D.S.I.R. recognizes what not every control engineer will accept — that ergonomics comes within his range of concern. The case for this view is put fairly satisfactorily in the Department's recently-published pamphlet *Ergonomics of automation*, which you can get from H.M.S.O. for 3s 6d.

POSSIBLY INFLUENCED by the attraction of the Hampshire countryside, I have for some time felt drawn to visit Roke Manor, the rural home of the Plessey Research Unit. Recently an opportunity came my way, and, although the Manor was having a face-lift at the time, I was not disappointed. My first glimpses through the windows did, I admit, give me an impression of incongruity — I saw electronic boxes and studious boffins where dignified butlers with silver trays would have looked more fitting—but once I got inside I found the research-lab atmosphere seemed natural enough.

The acquisition of the Manor marked something of a change in Plessey's research policy. They felt that they needed an environment for uninterrupted long-term work on the more basic research programs, away from the possible influences of production and sales departments. Roke Manor's research manager, Mr H. J. Finden, told me that the new policy has paid off, and he seems well satisfied with the team that he has got together. Not all of Plessey's researchers are in the original house; new labs have been built in the grounds to the maximum allowed by the planning people, and an extension is being put up elsewhere. However inconvenient, this is perhaps as it

should be, if the Manor grounds are to keep their attraction.

I came away feeling that a praiseworthy effort is being made at Roke Manor to match work to the individual—in fact, lines of research have sometimes been started to suit the inclination and abilities of a particular person. The general policy is to let research workers stick to their projects, possibly following through to the development stage elsewhere.

Plessey's did not pioneer the stately-home research technique, but they seem to be applying it well. I think this sort of thing may yet provide the answer to the problem of pursuing a technical career without developing neuroses.

A LONG TIME AGO my masters tried to explain to me the difference between physics and chemistry, but they left me unconvinced. In later years I found that a fairly sound way of distinguishing between the two subjects was to say that physics experiments were experiments I liked and chemistry experiments were experiments I did not like. In the lecture room I found that the only chemistry that caught my interest was in fact the physical kind. Yet the very existence of physical chemistry makes it plain that any borderline between its two parts must be mostly in the mind.

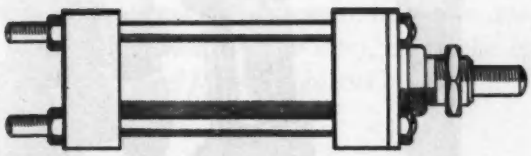
Consequently, when I approached certain well-known gates in Teddington last month, I found myself faintly irritated by the juxtaposition of the two name-plates; one said *National Physical Laboratory* and the other *National Chemical Laboratory*. Surely, whispered an imp inside me, these departments had by now been merged in the best scientific circles! On penetrating to the N.C.L. itself, however, to see what it had to show for its open days, I found that all was well —a substantial proportion of the work is very much concerned with physical measurements (or experiments I like).

I gathered from my walk-round that, while there is perhaps not much to show just yet, in another year's time the story may be very different. Good luck to Dr Anderson, the Director: he seems to be a man with ideas.

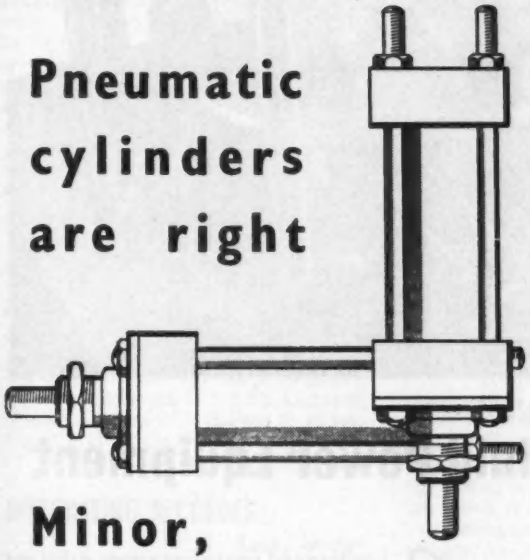
THIS HAS HAPPENED over and over again, of course, but I still found myself titillated by one of the latest examples of invention nearly enough simultaneous in quite different places. This turned up at last September's international conference on operational research, held in Aix-en-Provence. A British delegate (from the steel industry) read a paper about a combination of Boolean and matrix algebra to deal with a problem in a Bessemer shop. When the paper had been delivered the discussion was opened by a professor from Japan. Yes, he said, they had independently developed a very similar technique over there, for studying electrical networks.

Circle No 81 on reply card for further details

WHATEVER THE ANGLE

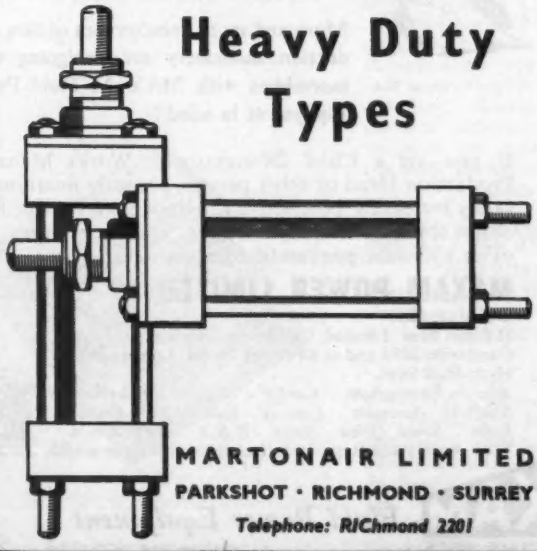


MARTONAIR



Pneumatic cylinders are right

Minor, Standard and Heavy Duty Types



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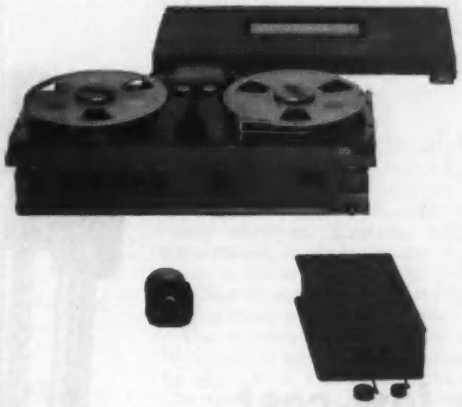
Telephone: RIChmond 2201

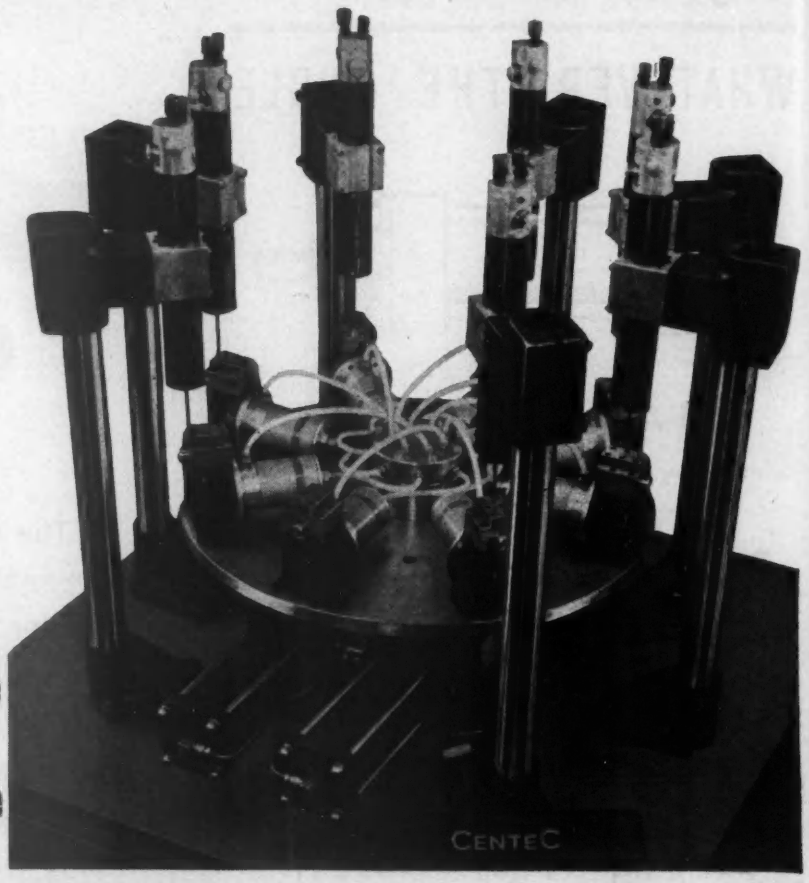
Circle No 82 on reply card for further details



The AMPEX AR-200

is an analogue magnetic tape recorder for airborne or mobile use. A completely integrated system, it occupies just 1.6 cubic feet of space and weighs only 95 pounds. The AR-200 performs reliably from −54° C. to +71° C., at altitudes to 100,000 feet, and will withstand 15g shocks and 10g vibration. Electronics are all solid state, and the recorder operates on 28 volts DC. Converters are available for use with other power sources. Standard speeds are 1⅞, 3¾, 7½, 15, 30 and 60 inches per second. The AR-200 can be used for direct, FM-carrier, PDM or digital recording. Models are available for up to 14 analogue tracks or 16 digital tracks. I. R. I. G. compatible at no extra cost. For specifications write to Ampex Great Britain Limited, Arkwright Road, Reading, Berks., England. AMPEX

For low-cost automation Centec Machine Tools Ltd. chose standard MAXAM Fluid Power Equipment



Flexibility and dependability at low cost was the theme of the Centec exhibit at the European Machine Tools Exhibition, 1959.

A multi-station rotary transfer machine built entirely of standard components demonstrated that automation need not necessarily be expensive. A 7-station design was assembled for the occasion. The eighth position on the rotary table was provided for loading and unloading the workpieces. Drilling seven holes ½-inch diameter at $\frac{3}{16}$-inch centres in a brass rod, total machining time was 7½ seconds.

Basically, the machine consisted of a standardised Centec rotary indexing table with component clamping and sequence control operated by standard MAXAM cylinders and valves. Par-A-matic drill units were supported on pillars at the drilling stations.

The demonstration proved conclusively that low-cost automation is capable of wide application, and needs skilled labour for the initial setting operation only.

Loading and unloading were carried out by unskilled personnel, but even these stages can be hopper-fed if required.

More and more constructors of flow production machinery are designing their assemblies with MAXAM Fluid Power Equipment in mind!

If you are a Chief Draughtsman, Works Manager, Production Head or other person seriously interested in safely increasing productivity, please send for our literature covering standard valves, cylinders, rams and other hydraulic/pneumatic equipment.

MAXAM POWER LIMITED

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MAXAM REGISTERED TRADE MARK *Fluid Power Equipment*

MA12

New for Control

A monthly review of system components and instruments: for further information on any item, circle the appropriate number on the reply card facing page 194.

SIGNAL GENERATOR
very low frequencies

A signal generator has a frequency range from 0·03 to 30 c/s, and gives four phase-related output signals (identical in frequency) simultaneously. The standard output is steplessly variable from 500 μV to 50 V (peak) using stepped and slide-wire attenuators. The reference and quadrature outputs, used for phase measurement, have a fixed level of 12 V, the reference being in phase with the standard output. The fourth output is variable in phase with respect to the standard output, and may be varied over a 20-dB amplitude range to a maximum of 20 V (peak).

The basic generator is a motor-driven capacitor which modulates a high-frequency signal, the modulated signal being rectified and amplified to provide the output. The motor speed is indicated on a 6-in. diameter scale on the front panel. The Airmec model 257 has a frequency calibration accuracy of ± 1·5% f.s.d., and harmonic distortion is claimed to be less than 2% at all frequencies.

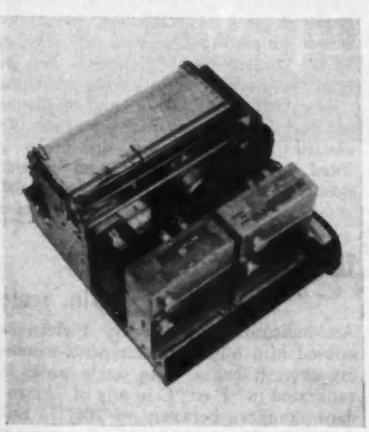
Circle **No 513** on reply card

INTEGRATING RECORDER
fast, linear

An integrating strip-chart recorder by Texas Instruments (U.S.A.) has five maximum count-rates, up to a maximum of 40,000 area-counts per min; linearity is ± 0·5 % full scale.

The integrator channel consists of a potentiometer-amplifier-servo system, and automatically activates an 'area trace' simultaneously with the main trace.

Circle **No 514** on reply card



Adjustable gear-system

TEMPERATURE CONTROLLER
transistorized

Avaialable from Control Instruments, the model-300 on-off controller has a 6-in. horizontal scale with a calibrated accuracy of ± 1%. Sensitivity is given as 0·15% of full scale.

The single-pole changeover relay has standard contact ratings of 5-A, 250-V a.c., but 15-A, 250-V a.c. contacts may be fitted to order. Calibration is for 2 Ω external resistance, and a pre-set resistor provides for variations of ± 5 Ω. Standard scale-ranges are 0–350 to 0–1200°C for C/A thermocouples, 0–600 and 0–800°C for I/C thermocouples, and 0–1200 and 0–1600°C for Platinum/Rhodium thermocouples. Power supply required is 200–260 V, 50–60 c/s.

Circle **No 515** on reply card

MAGNETOSTRICTION DELAY-LINE
variable, accurate

Recently introduced by Ferranti from the U.S.A. is a magnetostriction delay-line which is available with delays variable throughout the range of 2 μsec to 10 msec. The line has a maximum digit-rate of 500 kc/s, and delay-time fluctuation is less than 1 mμsec. Settings of delay are linear, and reproducible with an accuracy of 0·1%.

Continuous variation of delay-time is obtained by a mechanical control, through a low-torque, recirculating ball-race drive, suitable for manual or servo operation. Micro-switches provide an electrical indication when the limits of variation are reached, and mechanical end-stops prevent over-driving.

Circle **No 516** on reply card

DOUBLE POLE SWITCH
illuminated push-button

A unit by Square D consists of a double-circuit push-button switch, with a 6- to 8-V pilot light fed from an incorporated transformer.

The pilot-light lens, when depressed, operates a single-pole double-throw contact block. The illumination circuit is completely separate from the main switching-circuit, and may be arranged to illuminate the button only when the lens is depressed, or to remain 'on' once the lens has been depressed. Units are available for operation from 25- to 60-c/s supplies, at voltages between 110 and 600 V. Main contacts are rated up to 6 A a.c. or 2·2 A d.c., depending upon voltage.

Circle **No 517** on reply card

MINIATURE RECORDER
electrical input

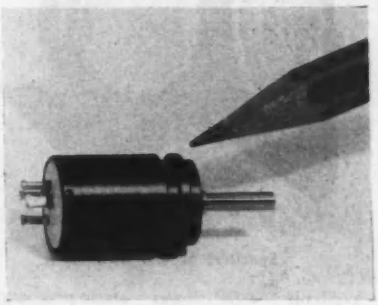
Shortly to be offered by Taylor Controls is an electronic version of their Transcope recorder. A complete range of measuring elements, actuating differential transformers, is available, the output of which is converted to a 1- to 5-mA d.c. transmission-signal by a field-mounted transistorized feedback-amplifier.

The recorder uses a 2-phase, size-15, 50-c/s, 117-V servo-motor; this is coupled by gears to a feedback potentiometer. The servo-units are sensitive to changes of 0·1% in the electrical input-signal. The strip-chart is 4-in. wide, and gives a 30-day continuous record. The controller may be supplied with proportional-plus-reset responses, or with pre-act responses in addition; rotary switches on the front panel of the plug-in chassis provide step-adjustment of the three responses.

Circle **No 518** on reply card

PRECISION POTENTIOMETER
½-in. diameter

A size 05 servo- or bush-mounted potentiometer, has a sleeve-bearing bushing mount or sleeve-bearing servo mount. Stops can be inserted at 340°, 320° and 300° as standard, and the unit may be sealed to specification MIL-E5272A. Maximum resistance available is 20,000 Ω, with tappings in 3 positions as required.



Small, accurate

Best practical resistance tolerance is ± 1%, and best practical linearities are ± 0·5% (100 to 1000 Ω), ± 0·4% (1000 to 10,000 Ω), ± 0·3% (10,000 to 20,000 Ω). Made by General Controls, the power rating is 2·0 W, derating down to zero at 80°C.

Circle **No 519** on reply card

SILICA ANALYSER
continuous operation

Designed for checking the silica content of boiler feed-water, an instrument by Electronic Instruments has an analysis cycle-time of 12 minutes. It is essentially a colorimeter, in which the colour of a solution to which reagents have been added is a measure of the concentration

of silica. A measured sample of water is taken automatically, a fixed volume of molybdate solution is added, and then the reducing agent. The stirred mixture turns blue, and is then delivered to an optical comparator and the blue shade photo-electrically compared with a Perspex blank or, if the water is discoloured, with the orignal water.

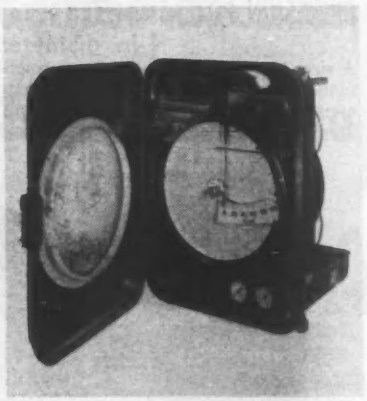
The instrument is available in three ranges: 0 to 0·2 parts of silica per million of water, 0 to 2·5 p.p.m., and 0 to 30 p.p.m. The differential output of the photocells in the colorimeter is fed to a transistor amplifier, whose output is 1 mA into 1500 Ω for full-scale deflexion. The whole sequence is automatically controlled by a mechanical program-timer.

Circle **No 520** on reply card

FLOWMETER

ring-balance system

A range of ring-balance meters features high sensitivity at low flow-rates. Ring assemblies are interchangeable to give full-scale differential-pressure ranges from 0·5 to 560 in. w.g., over static pressure ranges from 5 to 6000 lb/in². (The higher sensitivities are necessarily only



Sensitive at low flow

available with lower static-pressure ratings.)

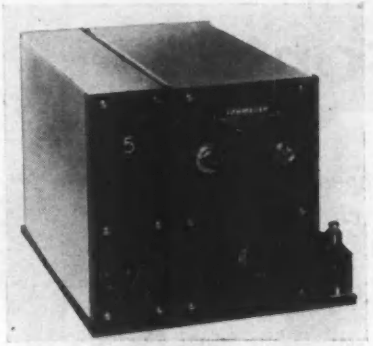
Available from Hagan Controls, the accuracy of the standard models is ±0·5% for 20%–100% maximum flow, and ready readability is claimed down to about 10% maximum flow. Accurate measurement may be made of flows down to 100 gal/h water, and the differential pressure range of any unit may be changed without disconnexion over a 3:1 ratio, representing a change in flow-range of approximately 1·9:1.

Circle **No 521** on reply card

BATCH COUNTER

illuminated digital display

Capable of count-rates up to 3000 per minute, a counter by Trumeter consists of a basic power-unit with one or more counting units (one for each decade). The digits, which are $\frac{7}{16}$ in. high, may be illuminated from within if necessary, and a push-button resetting facility is provided.



Fast count-rate

The basis of the device is a recently developed high-speed step-motor; it is claimed to have an exceptionally long life, and is 'plug-in' constructed.

Circle **No 522** on reply card

TIME INDICATORS

electrochemical

A series of compact elapsed-time indicators, for the recording of the total operating time of electrical equipment, is introduced by Industrial Instruments.

Known as the Selachron range, they are suitable for either a.c. or d.c. operation, and are available in sizes for use with voltages of from 6 to 300 V. The indicators use no moving parts and consist of cartridges which contain small, replaceable electrochemical cells, embodying an anode, cathode and electrolyte. The anode is consumed as current passes through the cell, the length diminishing in proportion to the accumulated hours of operation, this being shown by a calibrated scale alongside the anode. The length of each indicator is 2¼ in., the diameter being 1 in.; weight is less than 2 oz.

Circle **No 523** on reply card

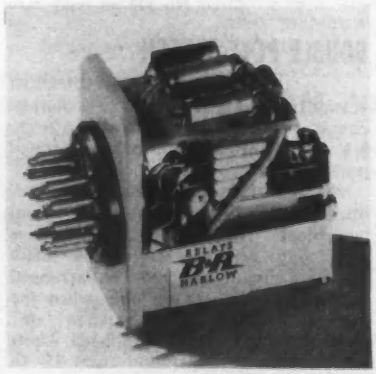
TRANSISTORIZED RELAY

3-stage amplifier

A 3-stage transistor amplifier produced by B. and R. Relays fits integrally with their M.01 relay, resulting in the M.01/T plug-in unit.

An operating sensitivity of the order of 5 μA may be achieved, and the power consumption is 0·5 W at a nominal 6 or

Operates from 5-μA signal



12 V d.c. The complete unit weighs 6 oz, and allows multiple ancillary circuit operation on receipt of a signal as low as 10 μW at the input.

Circle **No 524** on reply card

FREQUENCY METER

wide range, direct reading

A direct-reading frequency-meter may also be used as a signal generator. It measures or generates frequencies from 1000 c/s to 3000 Mc/s, and the stability (depending upon the crystal used) is between 2 parts in 10^{-8} and 4 parts in 10^{-10}.

Made by Telemechanics, the T.D.1 is transportable and the standard model has an accuracy of 2 parts in 10^{-8} after one hour. Internal impedance is 75 Ω, and the output voltage on fundamental frequencies is 100 mV. Spurious frequency level is − 80 dB.

Circle **No 525** on reply card

DIAL INDICATORS

square flanges

Two indicators by Ketay have 3-in. diameter dials and operate from a.c. synchronous transmission. Standard calibration is 0–360° in 2° intervals, but alternative scaling is available. Well-damped size-11, -15, or -18 synchro torque-receivers are used, giving a short settling time. Accuracy is normally ± 1°.

Synchro torque-transmitters complementary to the receivers specified are available for 50–60 or 400 c/s; also special models for use where several indicators are to be operated from one source.

Circle **No 526** on reply card

LINEAR ACTUATOR

load-sensitive

An electromechanical device by Teleflex Products has a 750-lb power-output, and a ram speed of 24 or 12 in/min depending upon the motor used. Load cut-out switches are arranged so that the actuator will build up and hold a pre-set load on the object to which it is attached. Control-position indication is fitted as required, using a variable-reactance transmitter coupled to a moving coil receiver at the control panel. Slidewires may be fitted in place of the variable reactance.

Standard stroke is 9 in., and the actuator may be mounted in any position. An electrically-released twin disk-brake is fitted to check over-run and provide positive locking in any position of stroke.

Circle **No 527** on reply card

TEMPERATURE CONTROLLER

13-in. scale

An indicator/controller by Fielden is housed in a 6-in. diameter panel-mounting case. It has a 13-in. scale which is calibrated in °F or °C in any of 73 standard ranges between − 200°C and + 850°C. The control point is set by a pointer operated from the knob at the

that's that

(magnified 7 times)

Precision

Here is a typical C.I. number wheel and pinion, actual size and enlarged 7 times, to show its crisp clean moulding which reduces wear potential to a minimum. Precision is such that length of boss and diameter of bore, concentricity of guide rim and other vital statistics are held to within .02 m/m.

Wide Range

C.I. wheels are available from 32 m/m to 14 m/m diameter and are held in stock in a wide range of standard styles and types. All wheels have sunken figures filled with a contrasting material which is resistant to the usual cleaning fluids, including petrol.

Competitive Prices

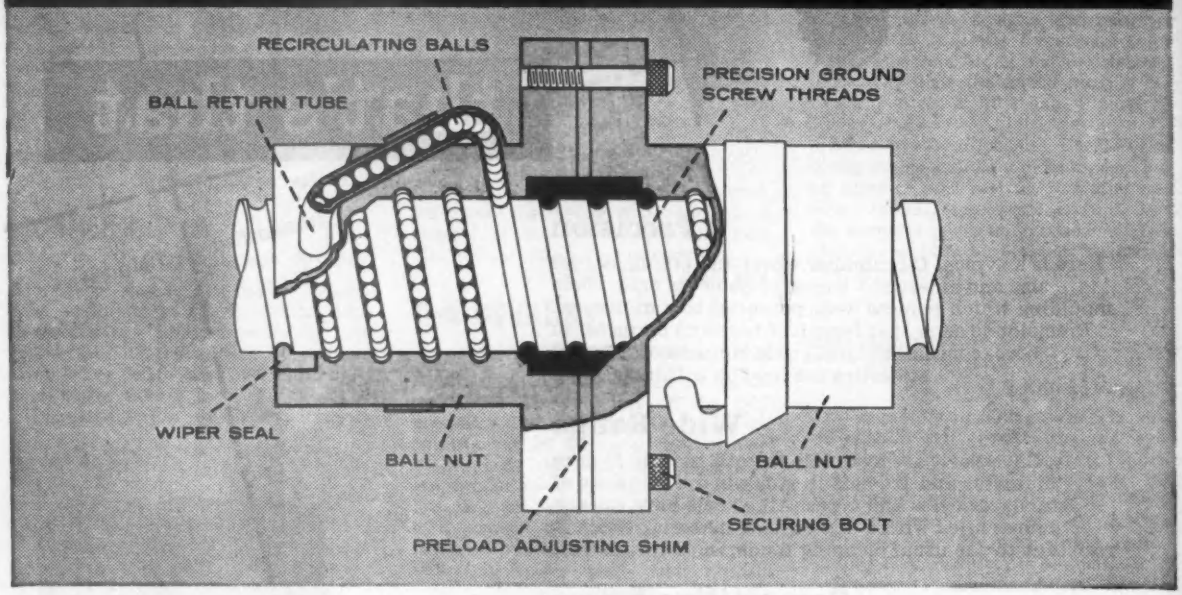
C.I. standard wheels and pinions will stand up to any competition, pricewise, and this also applies to items made to customer's own specification (C.I. toolroom facilities are specially designed for this purpose).

number wheels & pinions

COUNTING INSTRUMENTS LIMITED

ELSTREE WAY, BOREHAM WOOD, HERTFORDSHIRE. Tel: Elstree 1382

Beaver pre-loaded ball screws, up to 95% efficient, operate at -52°C to over 400°C with no backlash...



...ANOTHER ENGINEERING ADVANCE FROM BRISTOL SIDDELEY

Bristol Siddeley Engines Limited produce Beaver* pre-loaded ball screws. These ball screws achieve a minimum efficiency of 90% and they can operate within a temperature range of −52° C to 400° C without lubrication, and up to 170° C when lubricated.

Machined and ground to the highest standards of precision engineering Beaver pre-loaded ball screws greatly increase transmission efficiency. They reduce the power required for actuation by as much as 80%, when converting rotary drive into linear output or force input into torque output. By eliminating backlash, with pre-loading, they give precise control over very small increments of motion and a high response frequency. And when compared to conventional screw mechanisms, they provide a predictable operating life which is much longer, require much less maintenance and give more trouble-free operation.

Basic design application analysis

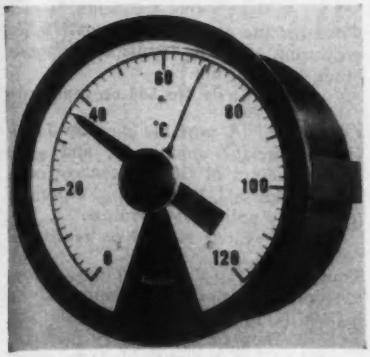
Bristol Siddeley engineers make an exhaustive analysis of each specification. And each unit is specially designed for its particular application. Beaver ball screws are made automatically reversible or with controlled "no-back," with multiple or single circuits. Beaver pre-loaded ball screws have been proved as the most efficient method of converting rotary into linear thrust in over 2,700 engineering applications in many branches of industry. They have been designed already with rated operating load capacities of 370,000 lb (825,000 lb maximum static load) but the maximum potential operating load is, in most cases, limited only by the requirement.

Bristol Siddeley Beaver ball splines have been developed to eliminate the disadvantages of conventional splines. The designs are very effective in minimising friction, particularly when high torsional and bending loads are imposed during linear movement.

** Complete technical and manufacturing co-operation with Beaver Precision Products Inc., Detroit.*

For further information please write to J. B. Starky, Sales Manager, Ball Screws and Splines, Bristol Siddeley Engines Limited, PO Box 17, Coventry, England.

BRISTOL SIDDELEY ENGINES LIMITED



Clear indication

dial centre, the indicating pointer being motor-driven by a servo-system.

The unit uses a platinum resistance-bulb housed in a ¼-in. diameter stainless-steel sheath, which may be located up to 300 ft away from the indicator. The control relay has contacts rated at 10 A, and provides changeover and 'normally-open' switching. The unit is transistorized and can be operated from 12 V d.c., or normal mains supply.

Circle **No 528** on reply card

PULSE GENERATOR
high repetition-rate

A pulse generator by du Mont (U.S.A.) provides a steplessly-variable output at rates up to 100,000 pulses/sec. Rise and fall times are 0·02 and 0·025 μsec (maximum) respectively, and pulse-width range is 0·05 to 100 μsec. Facilities are provided for pulse-delay before or after trigger, and there is a trigger output for synchronizing external equipment.

The model 404 is available in the U.K.

Fast rise-time

from Aveley Electric, and will work from any normal mains supply; consumption is 600 W.

Circle **No 529** on reply card

QUICK LOOKS

Pressure indicator. A unit by the Wheelco Division of Barber-Colman (U.S.A.) uses a linear scale with a full-scale span between 4·9 and 5·5 mV. It has its own power supply, using a Zener diode voltage-control circuit.

Circle **No 530** on reply card

Electromagnetic counter. An addition to Lancashire Dynamo Electronic Product's F43 range of counters has first wheel digits 0 to 11. Two versions are available having maximum count speeds of 1500 and 2400 counts/min respectively.

Circle **No 531** on reply card

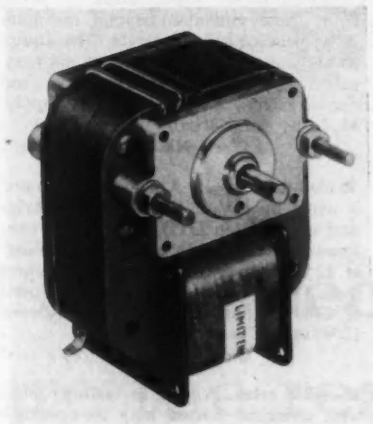
Pump-ram unit. A foot-operated unit by Linford Engineering is designed for elevating tables for machine-tools etc. Two ram-capacities are available, 1100 lb, and 1600 lb. Range of stroke-length is 6–47 in. to customer's requirements.

Circle **No 532** on reply card

Silicon rectifiers. An improved (smaller) design of their type SJ wire-ended junction rectifiers is available from A.E.I. (Rugby), to replace their form 'B' rectifier. The form 'F' has a flange of 1⅛ in., ⅛ in. less than the form 'B', but the ratings and prices remain the same.

Circle **No 533** on reply card

Shaded-pole motors. A range of skeleton-frame motors by Limit Engineering is available for 50- and 60-c/s supplies up



to 250 V. Torque outputs range from 1·25 oz in. to 7·2 oz in., continuous or intermittent ratings.

Circle **No 534** on reply card

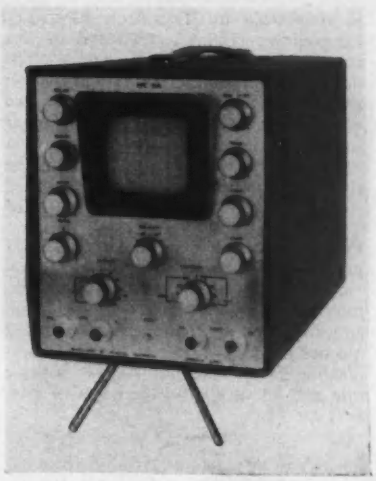
Level indicator. Designed for solids or viscous liquids, a circular-diaphragm bin-level indicator may be provided with single or double changeover switches rated at 5 A, 230 V a.c., 3 A, 440 V a.c., or 250 V d.c. (resistive loads). Made by Magco in three standard diameters, 6 in., 8¼ in., and 10½ in.; a square model is also available.

Circle **No 535** on reply card

Axial-flow fans. A range of fans by Service Electrical is available with impeller diameters from 2¾ to 11¼ in. Overall lengths for single-stage units are 2½ to 5¼ in. They may be supplied for use on all normal mains supplies, 50–400 c/s, 6 V d.c. for small fans, or with static inverters to run larger fans from d.c.

Circle **No 536** on reply card

Portable oscilloscope. A unit by Microcell has an internal battery capable of 8 hours continuous use, with a charging circuit which works from 200–250 V a.c. Bandwidth and sensitivity of the main y-axis amplifier are d.c. to 10 Mc/s and 100 mV/cm to 100 V/cm respectively. The y-axis pre-amplifier (bandwith 10



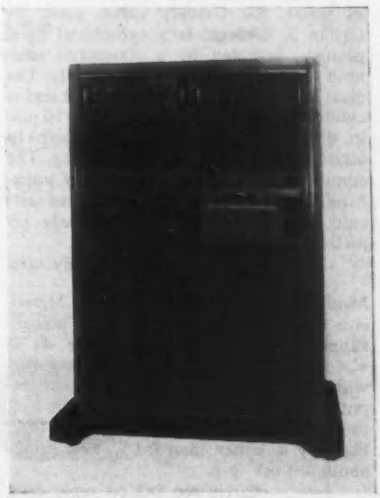
c/s–2 Mc/s) has a sensitivity of 10 to 30 mV/cm. Sweep range and width on the x-axis are 10 μsec–3 sec and 5 cm respectively.

Circle **No 537** on reply card

Miniature capacitors. Designed particularly for high-frequency application, Plessey's L.S.R. capacitors are suitable for transistor circuitry where low impedance at 10 kc/s or higher is essential. Seven ratings are at present available, with operational characteristics from 200 μF at 3 V working, to 12 μF at 12 V working, capacitance being measured at 50 c/s. These capacitors are claimed to be ideal in transistor computers, where discharge-current pulses of 1 μsec duration are encountered.

Circle **No 538** on reply card

Graph plotter. An addition to their existing range, Benson-Lehner's model QL enables its operator to take a 'quick look' at data recorded on punched cards or tape. Scales and offsets may be preset



digitally by push-buttons, and the machine will then plot up to 12 variables simultaneously at rates up to 2400 points/min.

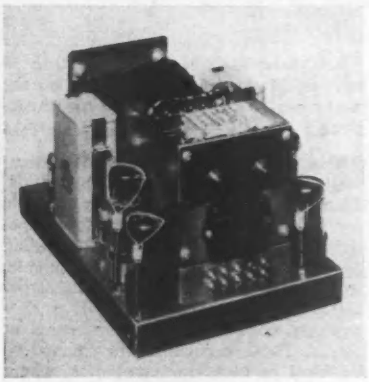
Circle **No 539** on reply card

Four-layer switching device. A semiconductor tetrode (binistor) developed for switching and storage-circuit applications

is announced by Transitron Electronic Corporation (U.S.A.), marketed in this country by Transitron Electronic. The device resembles the four-layer *p-n-p-n* switch, but differs in that it take the output from the intermediate *n* layer leaving the upper junction to serve as a latch to hold the device on when in the conducting state.

Circle **No 540** on reply card

Power supply. A twin unit by Servomex provides stabilized outputs of + 300 and −300 V d.c., at up to 50 mA, with a common zero point which may be used either earthed or floating. Also provided are two 6·3-V, 2-A, heater supplies. Stabilization factor is about 200 on positive side and about 400 on the negative side,



and mains input may be from 105–250 V, with sporadic changes up to ± 7% without loss of control.

Circle **No 541** on reply card

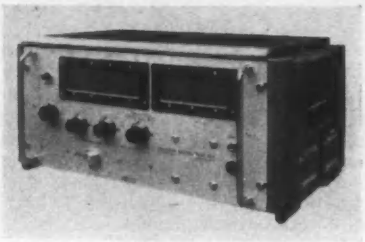
Solenoid valve. For use in flow systems as an on/off control where the maximum flow rate is 525 ml/min at 60 cm head of water, the Grundy valve, made by Griffin & George, is a cylindrical glass plunger, actuated by a concentric solenoid from a mains control-unit. The glass valve is 110 mm long overall and is cylindrical, being 70 mm long by 16 mm in diameter. It has rifled extensions to accommodate 5 mm diameter tubing. The control unit is a step-down mains transformer tapped at 12 V, with three circuits for controlling simultaneously up to three solenoids.

Circle **No 542** on reply card

Miniature power units. Made by Metrix is a range of stabilized transistor power-supplies. Overall dimensions are 4½ × 4 × 3½ in., and the units may be supplied with fixed or continuously variable output voltages between 0 and 24 V, at current ratings of 100, 300, or 500 mA. Stability is better than 0·1%, and ripple about 0·5 mV p-p.

Circle **No 543** on reply card

Resistor test-set. The nominal value of the resistor under test is set up by means of three switches, the value being displayed in digital form. The instrument measures the resistor on receipt of a command signal, and the percentage deviation from the pre-set nominal is



digitally indicated with its polarity. The reading time is 0·2 sec. The Solartron EM 1006 will handle resistors from 10 Ω to 15·9 MΩ, and the maximum indicated deviation is ±9·9%; accuracy and stability are guaranteed to be better than 0·1%.

Circle **No 544** on reply card

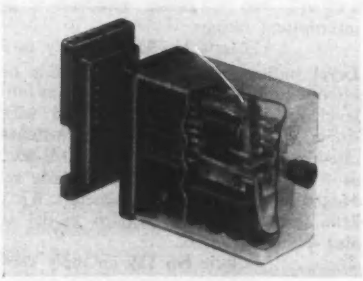
Thickness Gauge. An 8-mm magnetic thickness-gauge measures the thickness of steel tubes or plates. It permits rapid identification of sound tubes or plates from those corroded beyond the limit of a specified safety margin. The equipment, comprising a control unit and magnetizing probe, is transportable and operates from battery or mains supply. Made by Solus-Schall.

Circle **No 545** on reply card

Shaded-pole motor. A tropicalized motor is made by B.V.C. to Ministry of Aviation specification DTD 1085/B. It is continuously rated (with air-stream cooling) at 12 W, with 2 W output, and operates from 115/230 V a.c. to a maximum speed of 2700 rev/min. A 50-W version giving 12 W output is also available.

Circle **No 546** on reply card

Bi-stable relay. A plug-in latching-relay with electrical release may be operated from a.c. or d.c. supplies. Continuous ratings for main and de-latching coils



are are respectively 440 V a.c. or 250 V d.c. and 250 V a.c. or 125 V d.c. Up to five pairs of make or break contacts may be fitted in any combination. This Clifford and Snell tropicalized relay is marketed by D. Robinson.

Circle **No 547** on reply card

R.F. Oscillator. The DO 905 signal generator has a sine-wave output of constant amplitude over the range of 350 kc/s to 50 Mc/s. Variation in amplitude is claimed to be less than ±2% below 30 Mc/s, and less than ±5% above this. The frequency is steplessly variable in six ranges, and may be set to within ±2%. A 50-kc/s spot frequency is provided for use as a OdB reference when measuring amplifier frequency response. Made by Solartron.

Circle **No 548** on reply card

CO_2 tester. A portable unit by James Gordon weighs about 6 lb, and gives direct readings of CO_2 percentage on a 4-in circular dial. It is designed especially for use by untrained operators.

Circle **No 549** on reply card

Transistors. Two germanium alloy-junction transistors are announced by R.C.A. (G.B.), designated 2N1169 and 2N1170. They are designed for medium-speed bi-directional switching, and their collector-to-base voltage ratings are 25 and 40 V respectively.

Circle **No 550** on reply card

Variable transformer. A toroidally-wound unit by Philips is rated at 120 W, and has an output steplessly variable from 0 to 250 V at 500 mA nominal current. Available from Research and Control Instruments, the B8.709.59 is designed for use from 220- or 240-V, 50-c/s a.c. supplies. Circle **No 551** on reply card

Fork lifter. A mains-driven hydraulic lifter by Lodematic features an automatic start and stop mechanism. The platform rises to a predetermined height when loaded with a given weight, and falls at a controlled speed when the load is removed.

Circle **No 552** on reply card

INDUSTRIAL PUBLICATIONS

Radar tape-recorder. A leaflet from Decca Radar shows a recording system developed in conjunction with Ampex Electronics. Circle **No 553** on reply card

'Frame grid valves' is the title of a descriptive catalogue from Mullard.

Circle **No 554** on reply card

Switchgear by M.E.M. is comprehensively detailed in their 152-page list No 450. Circle **No 555** on reply card

'Programmed Industrial Control' is the title of a leaflet from Automation Engineering Systems describing their P.I.C. system. Circle **No 556** on reply card

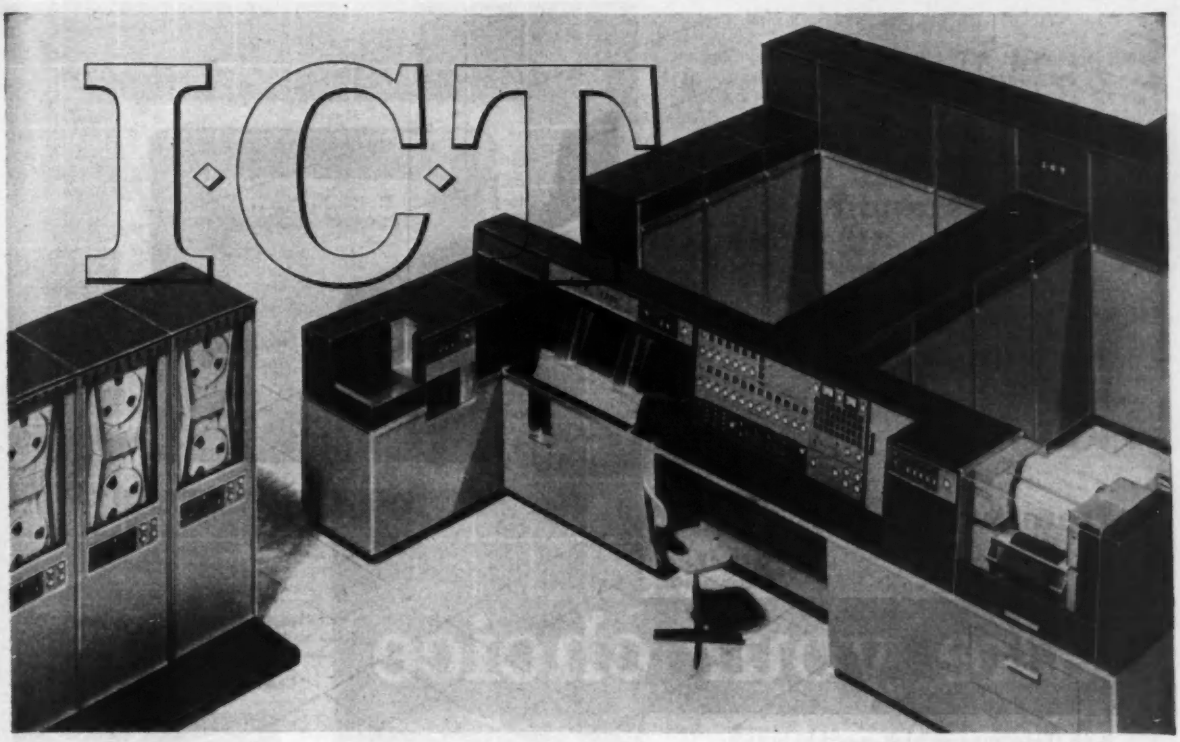
Equipment for railways by S.T.C. is shown in their 116-page publication Z/42. Circle **No 557** on reply card

Industrial electronic equipment is listed in a leaflet (4051-81) from A.E.I. (Rugby). Circle **No 558** on reply card

Pressure switches are the subject of catalogue 119/J from Londex.

Circle **No 559** on reply card

Annunciators. A catalogue (100 C) from Panellit describes the Panalarm annunciator system Circle **No 560** on reply card



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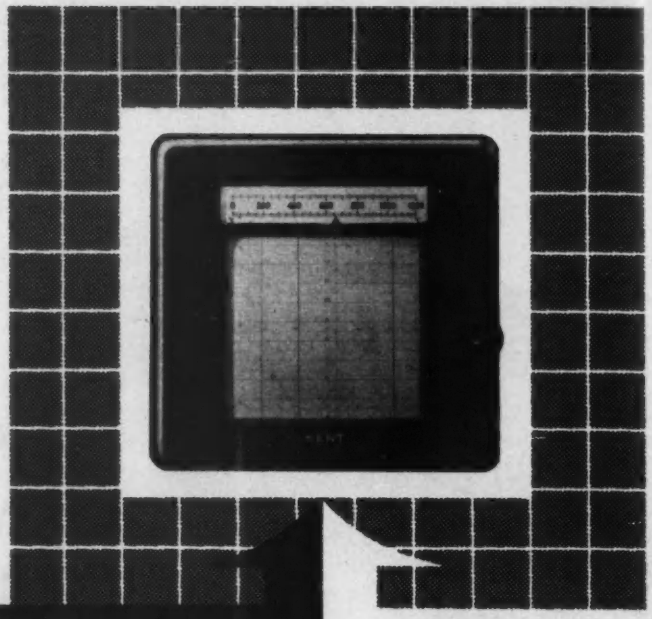
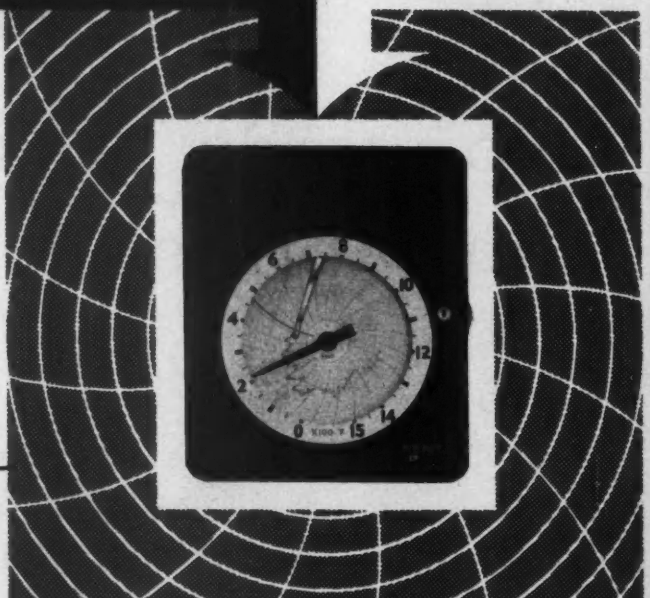


"Mark 3" indicator-recorder

"Commander KE" indicator-recorder



Both these modern high-speed indicator-recorders offer every user-advantage: plug-in modular construction, maximum accessibility, minimum maintenance etc. Both are available also as automatic controllers. Common electronic systems are employed, and the KENT series of amplifiers provides for a wide range of input conditions in temperature (thermo-couple etc.), millivoltage, oxygen-percentage and electrolytic-conductivity measurement. The *Mark 3*—strip-chart recording—is available in up to 16-point form, depending on application.
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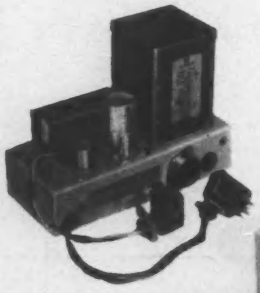

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Electro-pneumatic equipment by R.G.S. is listed in a recent catalogue.
Circle **No 561** on reply card

Dispersions of various types are described in a booklet from Acheson Colloids. Circle **No 562** on reply card

'Careers in the scientific instrument industry' is the title of a booklet issued by S.I.M.A. Circle **No 563** on reply card

Air-operated receivers for measurement and control are shown in catalogue B/21 from Negretti and Zambra.
Circle **No 564** on reply card

'The transformer ratio-arm bridge' is the title of a monograph by Raymond Calvert of Wayne Kerr.
Circle **No 565** on reply card

Technical bulletin. The first of a series to be published by Engelhard Industries contains technical articles and patent abstracts.
Circle **No 566** on reply card

'A.M.F.' A booklet describing the activities in Britain of the American Machine and Foundry Company International Group. Circle **No 567** on reply card

Process control. The Bailetronic system is described in publication No 295 from Bailey Meters and Controls.
Circle **No 568** on reply card

Pressure-reducing valves for steam and air are shown in a catalogue from Midland Industries.
Circle **No 569** on reply card

Transistors are a feature of a booklet from Associated Transistors entitled *'A new era'*, which describes the formation of the company.
Circle **No 570** on reply card

LOOKING AHEAD

Unless otherwise indicated, all events take place in London. B.C.S. British Computer Society. Brit.I.R.E. British Institution of Radio Engineers. I.E.E. Institution of Electrical Engineers. I.Mech.E. Institution of Mechanical Engineers. R.Ae.S. Royal Aeronautical Society. S.I.T. Society of Instrument Technology.

TUESDAY 8 NOVEMBER
Electronics in process control by C. G. Seeds and W. Barber. 7.00 p.m. Borough Polytechnic. Details: G. L. H. Bird, Borough Polytechnic, London, S.E.1.

WEDNESDAY 9 NOVEMBER
A shaft position digitizer using synchros by T. Roberts. 7 p.m. S.I.T.

The digital computer by I. Cochrane. Institution of Engineers and Shipbuilders, 39 Elmbank Cres., Glasgow. 6 p.m. I.E.E.

Modern computer techniques by K. C. Johnson. 7.15 p.m. Brit.I.R.E. College of Technology, Wulfruna Street, Wolverhampton.

Discrete analogue-computer compensation of sampled-data control systems by T. Glucharoff. Read by J. H. Westcott. 5 p.m. I.E.E.

TUESDAY 15 NOVEMBER
Automatic control of machine tools by J. W. Smith. 7.00 p.m. Borough Polytechnic. (See Tuesday 8 November).

WEDNESDAY 16 NOVEMBER
Digital computing elements for instructional use by Lt.-Col. I. W. Peck. 6.30 p.m. Brit.I.R.E., London.

THURSDAY 17 NOVEMBER
The control of a single effect concentrating evaporator — dynamic characteristics and analogue computer study by F. P. Lees, L. W. A. Glasson and J. A. Anderson. 7 p.m. S.I.T.

THURSDAY 17—SUNDAY 20 NOVEMBER
Ninth S.I.M.A. convention, Grand Hotel, Eastbourne. Details: S.I.M.A., 20 Queen Anne St., London, W.1.

FRIDAY 18 NOVEMBER
Magslips, synchros and their applications by J. H. Batchelor. The Large Lecture Theatre, The London School of Hygiene and Tropical Medicine, Keppel St., W.C.1. 7 p.m. Institution of Electronics.

Transistors in control circuits by E. Wolfendale. 7 p.m. Brit.I.R.E., School of Management Studies, Unity St., Bristol.

Radio aids for automatic landing developed by the Blind Landing Experimental Unit by J. S. Shayler. Brit.I.R.E. Farnborough Technical College, Farnborough, Hants.

MONDAY 21—WEDNESDAY 23 NOVEMBER
International seminar on *Analogue computation applied to the study of chemical processes*, Brussels. Details: R. Vichnevetsky, 43 rue de la Science, Bruxelles 4, Belgium.

TUESDAY 22 NOVEMBER
Automatic control of boiler house plant by P. J. Wheeler. 7.00 p.m. Borough Polytechnic. (See Tuesday 8 November).

TUESDAY 22—THURSDAY 24 NOVEMBER
Conference on electronic telephone exchanges. I.E.E.

MONDAY 28 NOVEMBER
An introduction to electronic computers by R. C. M. Barnes. Electric House, Ipswich. 6.30 p.m. I.E.E.

TUESDAY 29 NOVEMBER
Automatic control in the steel industry by M. H. Butterfield. 7.00 p.m. Borough Polytechnic. (See Tuesday 8 November).

Symposium on nuclear temperature scanning. *Temperature scanning equipment for a large nuclear reactor* by C. Hall. 7 p.m. S.I.T.

Temperature scanning equipment for use in a nuclear power station by A. G. Blay, P. G. Davey and F. C. Flint. 7 p.m. S.I.T.

FRIDAY 2 DECEMBER
Progress in microminiature circuit techniques for digital computers by D. Roberts, D. S. Campbell and P. M. Thompson. 6.30 p.m. Brit.I.R.E., London School of Hygiene and Tropical Medicine, Keppel St., London, W.C.1.

TUESDAY 13 DECEMBER
Analytical instrumentation of process gas streams by J. C. Hawkes. 7.30 p.m. Blossoms Hotel, Chester. Details: A. V. Bailey, 2 Finney Drive, Wilmslow, Cheshire. (I.Chem.E.).

WEDNESDAY 14 DECEMBER
Speed control of aircraft gas turbines for jet propulsion by R. J. Walsh and R. W. Haigh. 7 p.m. S.I.T.

WEDNESDAY 4 JANUARY 1961
Automatic techniques in civil air line communications systems by W. E. Brunt. 6.30 p.m. Brit.I.R.E., London School of Hygiene and Tropical Medicine, Keppel St., London, W.C.1.

MONDAY 9—WEDNESDAY 11 JANUARY 1961
7th National Symposium on Reliability and Quality Control. Bellevue-Stafford Hotel, Philadelphia, Pa., U.S.A.

MONDAY 16—FRIDAY 20 JANUARY 1961
Physical Society Exhibition, R.H.S. Halls, Westminster, London, S.W.1. (Probable dates).

WEDNESDAY 18 JANUARY 1961
A general method of digital network analysis particularly suitable for use with low-speed computers by M. N. John. 5.30 p.m. I.E.E.

Digital computers in power system analysis by P. P. Gupta and Professor M. W. Humphrey Davies. 5.30 p.m. I.E.E.

MONDAY 23 JANUARY 1961
Cybernetics by Professor J. C. West. Royal Institution, Colquitt St., Liverpool. 6.30 p.m. I.E.E.

TUESDAY 24 JANUARY 1961
Discussion on *Machine-tool control*. Opened by E. H. Frost-Smith. 5.30 p.m. I.E.E.

TUESDAY 31 JANUARY 1961
Instrumentation past, present and future by L. S. Yoxall. 7 p.m. S.I.T.

LOOKING FURTHER AHEAD

WEDNESDAY 15—FRIDAY 17 FEBRUARY 1961
1961 International Solid-state Circuits Conference. University of Pennsylvania and the Sheraton Hotel, Philadelphia, Pa., U.S.A.

MONDAY 16 FEBRUARY 1961
Transistors and all that by L. J. Davies. Central Hall, Westminster. I.E.E.

TUESDAY 17— SATURDAY 21 FEBRUARY 1961
24th International Components Show, Parc des Expositions, Paris.

MONDAY 20— THURSDAY 23 MARCH 1961
I.R.E. National Convention, New York.

TUESDAY 21—SATURDAY 25 MARCH 1961
10th Electrical Engineers Exhibition, Earls Court. Details: Mr Joyce, Electrical Engineers Exhibition, 6 Museum House, 25 Museum St., London, W.C.1.

MONDAY 27—FRIDAY 31 MARCH 1961
3rd National Symposium on Temperature, Its Measurement and Control in Science and Industry. Columbus, Ohio.

THURSDAY 20 APRIL—THURSDAY 4 MAY 1961
Engineering, Marine, Welding and Nuclear Energy Exhibition, Olympia.

WEDNESDAY 3—SATURDAY 13 MAY 1961
British Columbia International Trade Fair, Exhibition Park, Vancouver.

TUESDAY 9—WEDNESDAY 17 MAY 1961.
International Exhibition of Measurement, Control, Regulation and Automation (Mesucora) and 58th Exhibition of French Physical Society, C.N.I.T., Paris. Secrétariat Général, 40, rue de Colisée, Paris, 8.

TUESDAY 30 MAY—2 JUNE 1961
Radio and Electronic Component Show, Olympia. Details: Industrial Exhibitions Ltd., 9 Argylle St., London, W.1.

MONDAY 12—SATURDAY 17 JUNE 1961
Conference on *Components and materials used in electronic engineering*. Central Hall, Westminster, I.E.E.

MONDAY 26 JUNE—SATURDAY 1 JULY 1961
International Measurements Conference, (Imeko), Budapest. Details: Prof. J. F. Coales, Cambridge University, Trumpington St., Cambridge, or Imeko Secretariat, Budapest 5, P.O.B. 3.

MONDAY 4—SATURDAY 9 SEPTEMBER 1961
3rd International Sessions of the International Association for Analogue Computation. Belgrade, Yugoslavia. Details: Yugoslav Committee for Etan Terazije 23/VII, Belgrade, Yugoslavia.

MONDAY 4—SUNDAY 10 SEPTEMBER 1961
S.B.A.C. Flying display and exhibition, Farnborough. Details: S.B.A.C., 29 King St., St. James, London, S.W.1.

WEDNESDAY 6—FRIDAY 8 SEPTEMBER 1961
International Symposium on the *Transmission and processing of information*. Massachusetts Institute of Technology. Submission of papers is invited. Details: R. M. Fano, R.L.E., M.I.T., Cambridge 39, Mass., U.S.A.

MONDAY 11 SEPTEMBER 1961
20th International Congress of Navigation. Baltimore. Details: Permament International Association of Navigation Congresses, 60 rue Juste Lipse, Brussels.

Book Reviews

Automation

Progress in Automation. *Edited by* **Andrew D. Booth.** *Butterworths Scientific Publications. 1960. 231pp. £2 2s.*

Any scheme which makes knowledge available on specialized subjects without the need to study information from many technical journals deserves sympathetic consideration. This volume is the first of a series dealing with automation in its many aspects and each subject is to be covered by an expert in that field.

The editor of the series has provided a short historical introduction with definitions of a few of the terms. The remainder of the book is roughly equally divided between 'Methods' and 'Applications'. In the first part there are chapters on analogue-to-digital conversion, electronics in process control, position control in machine tools, and the Inductosyn; and two chapters on nucleonic gauges. In these chapters the emphasis is on technique of measurement, except in the case of process control. Here the discussion is mainly of possibilities, and one has the impression that the editor of that chapter has found it difficult to find examples that were 'automation' and not just 'automatic'. He does, however, include a bibliography that will help the interested reader to pursue the subject further.

In the section on applications, there are substantial chapters on the Ferranti and E.M.I. machine-tool controls, the latter including a good list of articles on a number of types of machine-tool control. Shorter chapters on the manufacture of steel strip and automatic inspection give some impression of catholicism.

This book represents an interesting approach to the very real problem of spreading technical knowledge, and is on the whole sucessful. Not all chapters have a comprehensive biography, and some would have been easier to read had there been more diagrams. The preoccupation of this volume with machine-tool control, which accounts for two-thirds of the 227 pages, is to be expected. In this field 'automation' as defined by the editor, 'duplicating the activities of living creatures, including humans, by non-living, but energy-consuming means', finds its most spectacular achievements.

Finally, the volume is well finished and has clear print and diagrams on a smooth baryta paper, and is sold for a modest sum by today's standards. Some readers would like the same clarity and cleanliness without the shine of this type of paper.

A. ASBURY

Instruments

Industrial Instrument Servicing Handbook *by* **G. C. Carroll.** *McGraw Hill Publishing Co. 1960. 810 pp. £6 4s*

Many valuable books have been published in recent years on industrial instruments. One of particular note is 'Messen und Regeln in der Chemischen Technik' by Hengstenberg, Sturm and Winkler, which surveys the whole field of industrial instruments from the measurement of pressure, level, velocity, pH, gas analysers, temperature, etc., describing throughout the pages of the volumes many of the instruments available commercially. The new book by Grady C. Carroll is similar in that the author surveys industrial instruments, giving detailed descriptions of most of the well-proved instruments available commercially; however, the work is aimed not at the designer but at the specialist servicing engineer.

The book is designed to provide the reader with the design principles, plus the service and maintenance procedures needed regularly in the shop or in the field. It treats in specific detail a wide variety of instruments and control mechanisms manufactured by over forty companies. Over fifty types of instrument are covered, and for each type there is explanation of the principles of operation and the best methods of servicing, maintaining, trouble-shooting and complete calibration. The scope of the handbook can be best seen by considering the titles of the main chapters: *Pressure-measuring Instruments, Differential Pressure-measuring Instruments, Liquid-level-measuring Instruments, Temperature-measuring Instruments, Viscosity and Specific-Gravity Instruments, pH Instruments, Gas Analysers, Control Valves and Valve Positioners,* and *Speed Measurement and Control.* The great majority of the currently available instruments are described, and many of the new instruments also find a place; for example, gamma-ray methods of level determination and specific-gravity determination are included. The book ends with a chapter providing valuable information on organizing an instrument-maintenance department and selecting its personnel, the author obviously drawing on his own personal experience as Chief Instrument Engineer, Energy Division at the Olin Mathieson Chemical Corporation in Niagara Falls, N.Y.

The book should prove a valuable addition to the library of everyone concerned with servicing, maintaining or calibrating industrial instruments. It provides many useful organization charts, scheduling systems for preventive maintenance, and trouble-shooting charts to assist in locating faulty components. It is well illustrated with photographs, line drawings, circuit diagrams, etc., and is easy to read in spite of the fact that the information presented has been obtained from many sources. To the reviewer it will be a useful work of reference.

DENIS TAYLOR

Masers

Masers *by* **J. R. Singer.** *John Wiley: New York. Chapman & Hall: London. 1959. 147 pp. £2 12s.*

During the past five years the maser has attracted much interest, both from the physicist as a research tool, and from the microwave engineer as an extremely-low-noise amplifier with applications to long-range radar and radio astronomy. If operated as an oscillator, the maser may be used as a frequency standard or as a source of radiation.

After a short introduction, Professor Singer gives an account of the theory of stimulated emission and absorption and shows how amplification may be achieved. There follows a description of the ammonia maser and atomic beam devices. A chapter on paramagnetic resonance leads to a discussion of the various types of solid-state maser, including travelling-wave devices. Both the theoretical principles and the practical details of design and construction are presented. Some experimental results are also quoted.

The book should serve as a very readable introduction to the subject. The addition of a list of references at the end of each chapter also provides an excellent guide to the literature. The book is attractively produced and contains many excellent diagrams which greatly facilitate understanding of the text.

E. D. FARMER

Literature Received

List of Publications available to the Public. *U.K.A.E.A. 1960. 173 pp. £1 3s.* ★ 704

Digital Computer and Control Engineering *by* **Robert Steven Ledley.** *McGraw Hill Publishing Co. Ltd. 1960. 835 pp. £5 12s. 6d.* ★ 705

Servomechanisms *by* **P. L. Taylor.** *Longmans, Green & Co. Ltd. 1960. 418 pp. £2 2s.* ★ 706

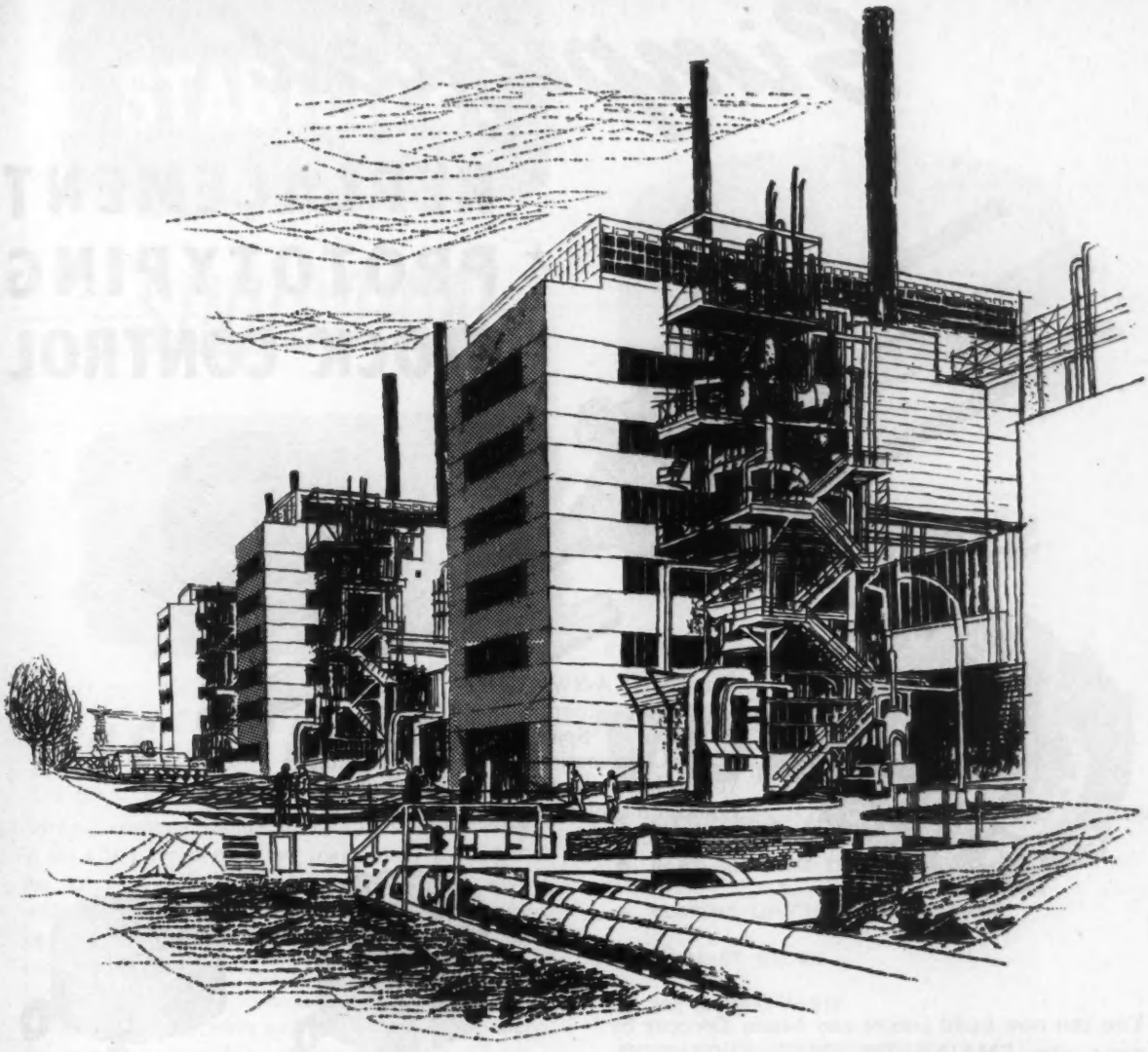
The Advance Science Masters Handbook *by* **Ivan L. Muter.** *Advance Components Ltd. 1960. 124 pp. 12s. 6d.* ★ 707

Automation and Skill *by* **E. R. F. W. Crossman.** *D.S.I.R. 1960. 60 pp. 3s. 6d.* ★ 708

Ergonomics of Automation *by* **A. T. Welford.** *D.S.I.R. 1960. 60 pp. 2s.* ★ 709

Nanosecond 100 ohm Delay System with Remote Control Facilities *by* **A. K. Barlow** *and* **J. F. Gibbs.** *U.K.A.E.A. 1960. 14 pp. 2s. 6d.* ★ 710

★ Circle the relevant number on the reader information card facing page 194 for further information.



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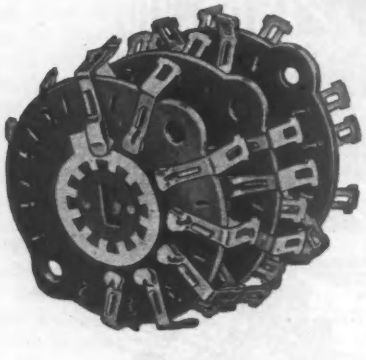

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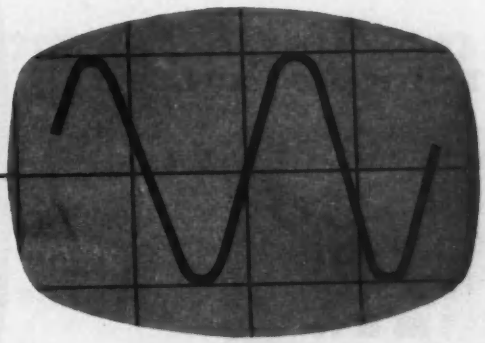

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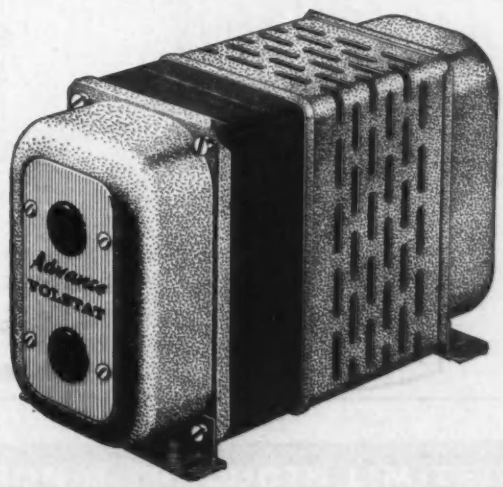
CVH420A	190–260 50~	240	420	1.00	£37. 0. 0
CVH750A	190–260 50~	240	750	1.00	£68. 0. 0
CVH1500A	190–260 50~	240	1500	1.00	£99. 0. 0
CVH3000A	190–260 50~	240	3000	1.00	£185. 0. 0
CVH6000A	190–260 50~	240	6000	1.00	£355. 0. 0

Full details in Folder G1 available on request



Advance COMPONENTS LIMITED

MAINS STABILIZATION DIVISION

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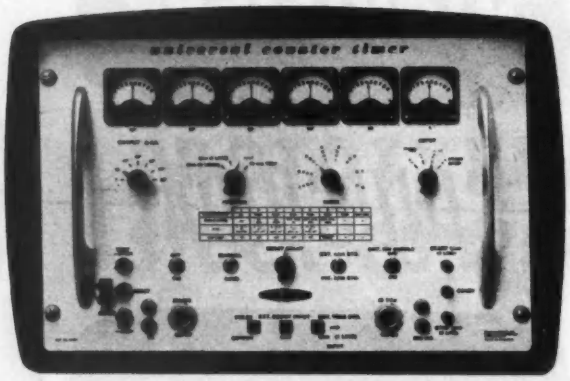
IT/Da

Transistorized UNIVERSAL COUNTER TIMER



Frequency Measurement

Random Counting

Frequency Division

Time Measurement

Frequency Standard

This fully transistorized portable equipment provides for a wide range of time and frequency measurement as well as facilities for counting, frequency division and the provision of standard frequencies. The facilities available are briefly listed below:

TIME/UNIT EVENT (1 LINE): For the measurement of the time interval between two occurrences in a continuously varying electrical function in the range 3μsec to 1sec. The time for 1, 10 or 100 such events can be measured.

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EVENTS/UNIT TIME: For frequency measurement in range 30c/s to 1Mc/s over period of 0·001, 0·01, 0·1, 1 or 10secs. Crystal accuracy ±2 parts in 10^6/week. For mains or 12Vd.c. operation.

Full technical specification available on request.

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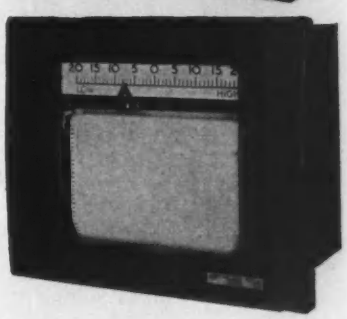
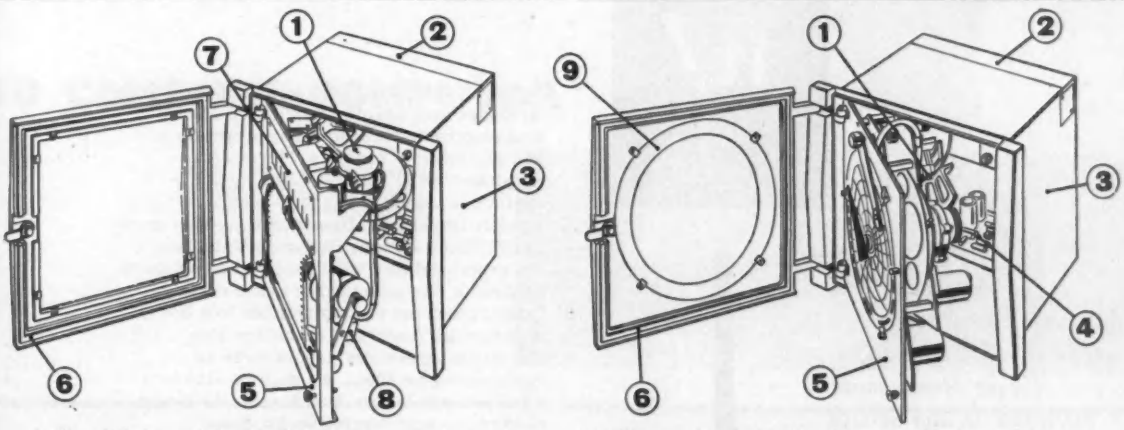
New servo rebalance indicator/recorders offer high performance at low cost

Available in 10″ circular chart and 10″ wide strip chart versions with 1 second full scale traverse and common mechanisms of simple rugged design providing a performance comparable with many more expensive instruments.



Both circular and strip chart versions are available with a wide range of measuring elements of all types–for temperature, pressure, flow, mechanical force, linear displacement. A special feature is the wide range of electrical measurements for which the instruments cater. A three-term control unit and associated electro-pneumatic valve positioner together with a comprehensive range of pneumatically operated valves are also offered in the form of completely integrated schemes.



1 Simplified pen drive mechanism
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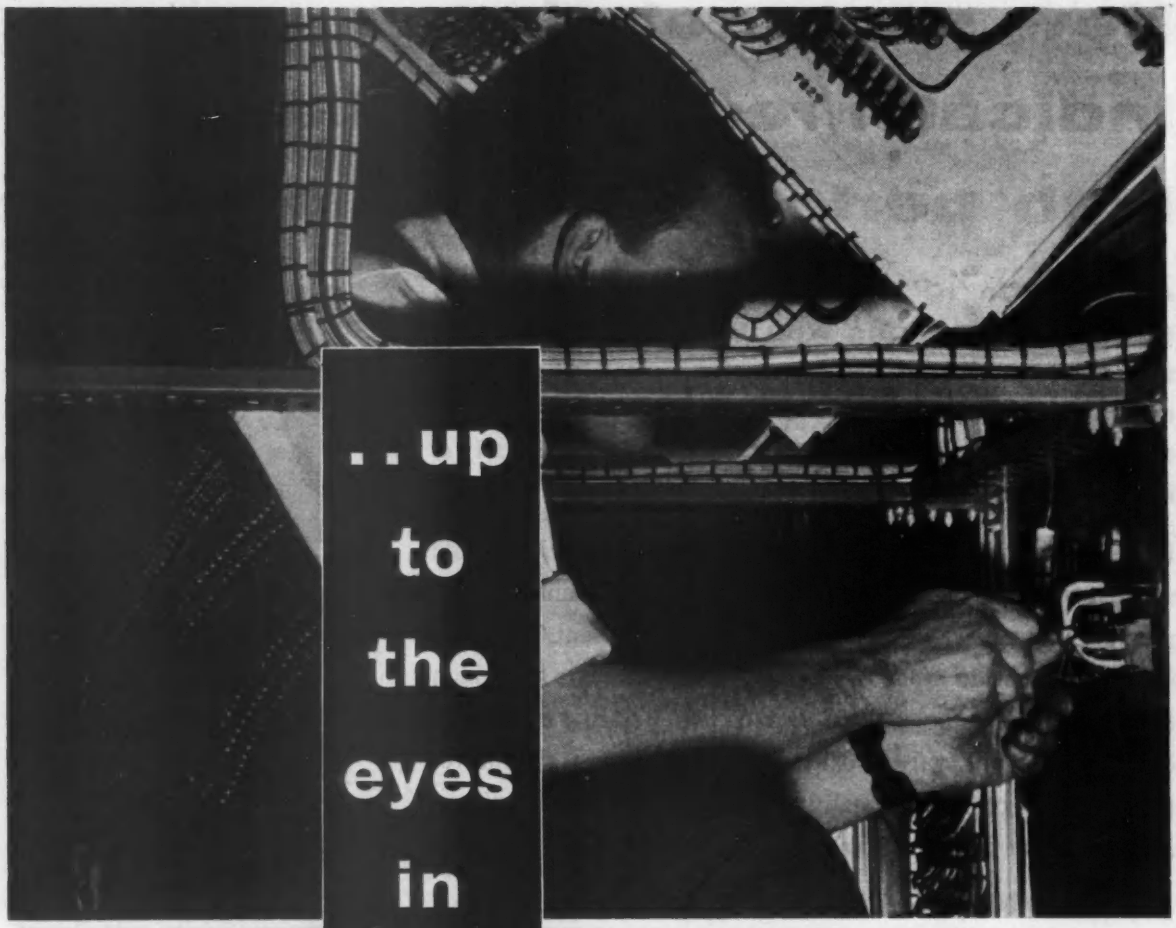

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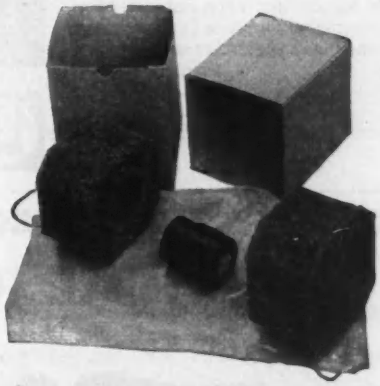

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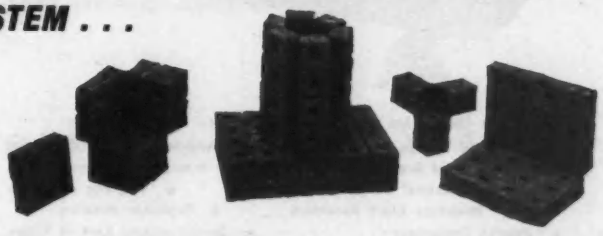

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THE Hairlok COMPANY LTD. Magna Works, Kathie Road, Bedford. Tel. Bedford 4271

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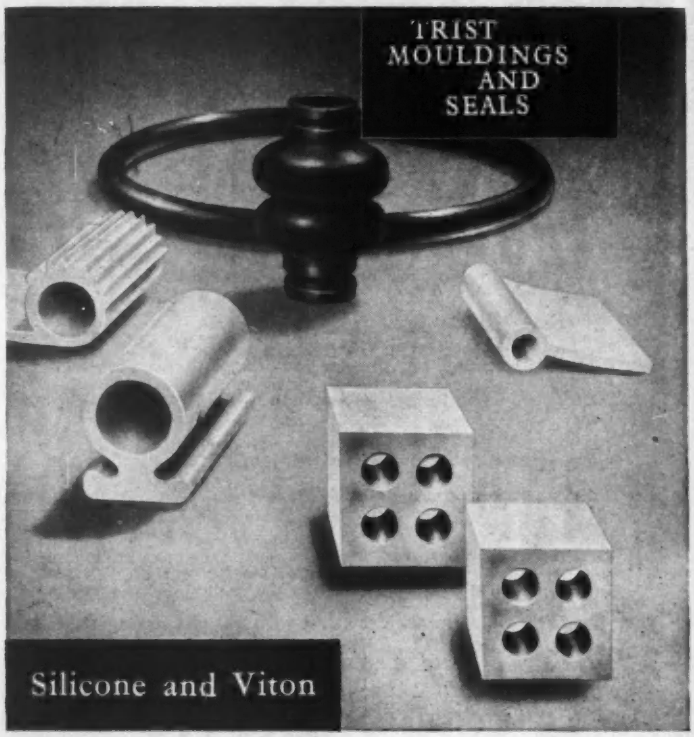

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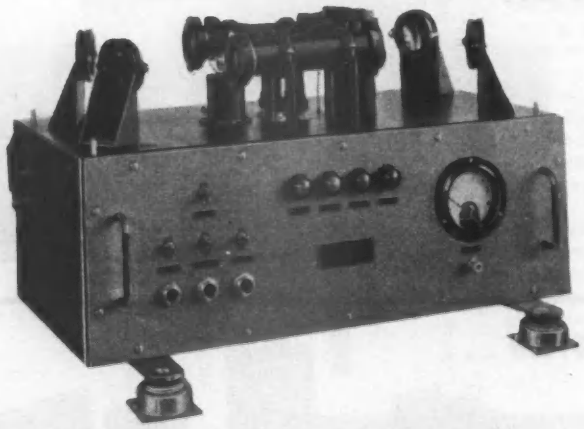
OPTICAL COMPARATOR
TYPE 801A



The Optical Comparator is designed for the detection of the variation in optical properties between two liquids, or one liquid and a reference, passing through the sampling tubes. A light beam originated from a common source is projected through the liquids and focused on balanced photo-cells so that differences are easily detected. Amplification of the signal is achieved in a magnetic amplifier stage which can be arranged to operate an alarm relay at a predetermined level of out-of-balance. The sensitivity is high and contaminations of oil in water of as low as two parts per million can be detected.

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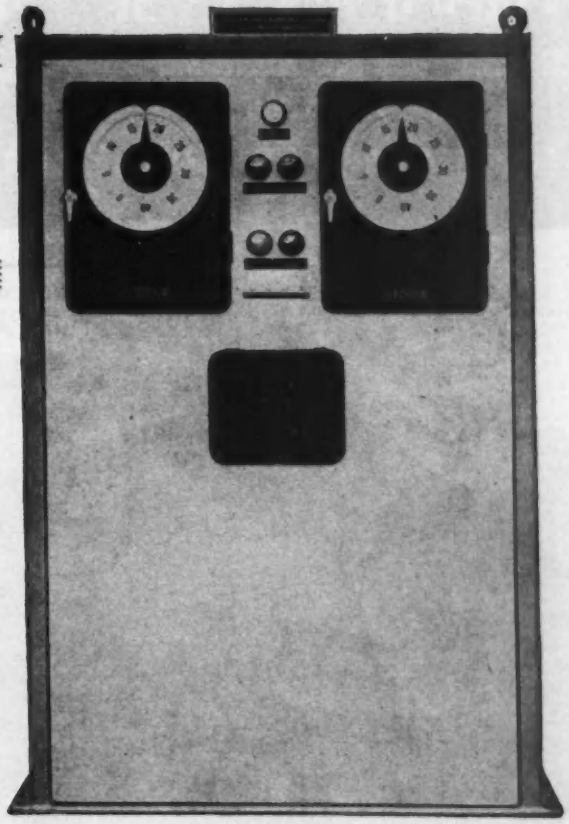
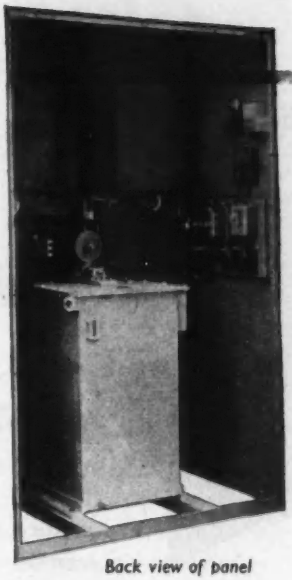
One of 8 panels manufactured for Barlow-Whitney Ltd.



Long term HIGH STABILITY TEMPERATURE CONTROL



Back view of panel

This equipment comprises a two term proportional electronic self-balancing indicating controller actuating a triple gang 10 K.W. voltage regulator complete with continuously monitoring indicating controller and a periodically monitoring unit (A.C.F.S.U.*) automatically testing the input and output of potentiometric circuit and the mechanical functioning of controller without interfering with normal control process, and causing, if fault exists, alarm and safeguarding action.

This device sends right through the controller measuring and balancing circuits, a periodical test signal which, should it fail to get through due to any electrical or mechanical fault in the controller, causes an alarm to be given and automatic safe-guarding action to be taken.

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LIMITED

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TYPE 2000 with on/off control
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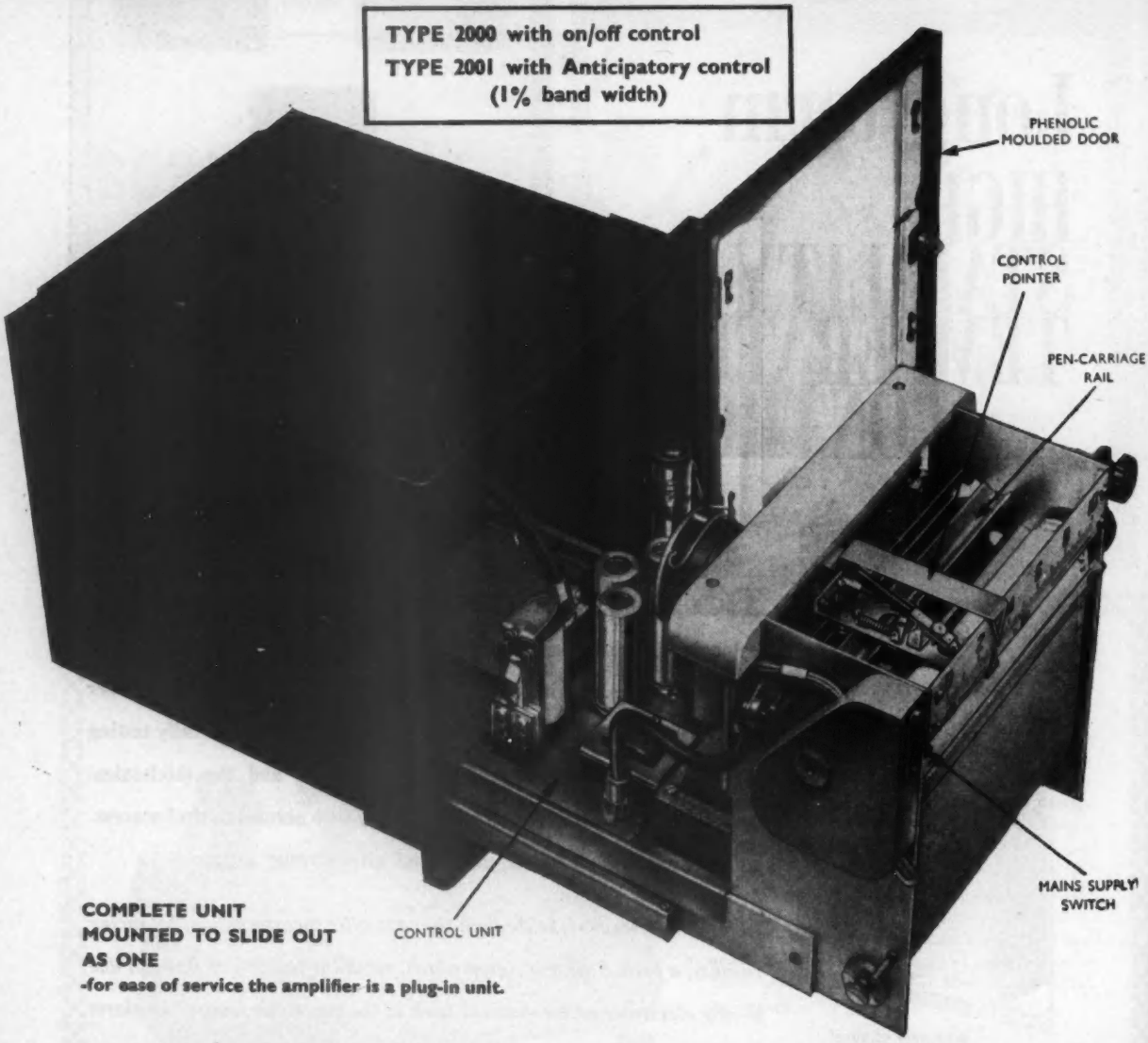
(1% band width)



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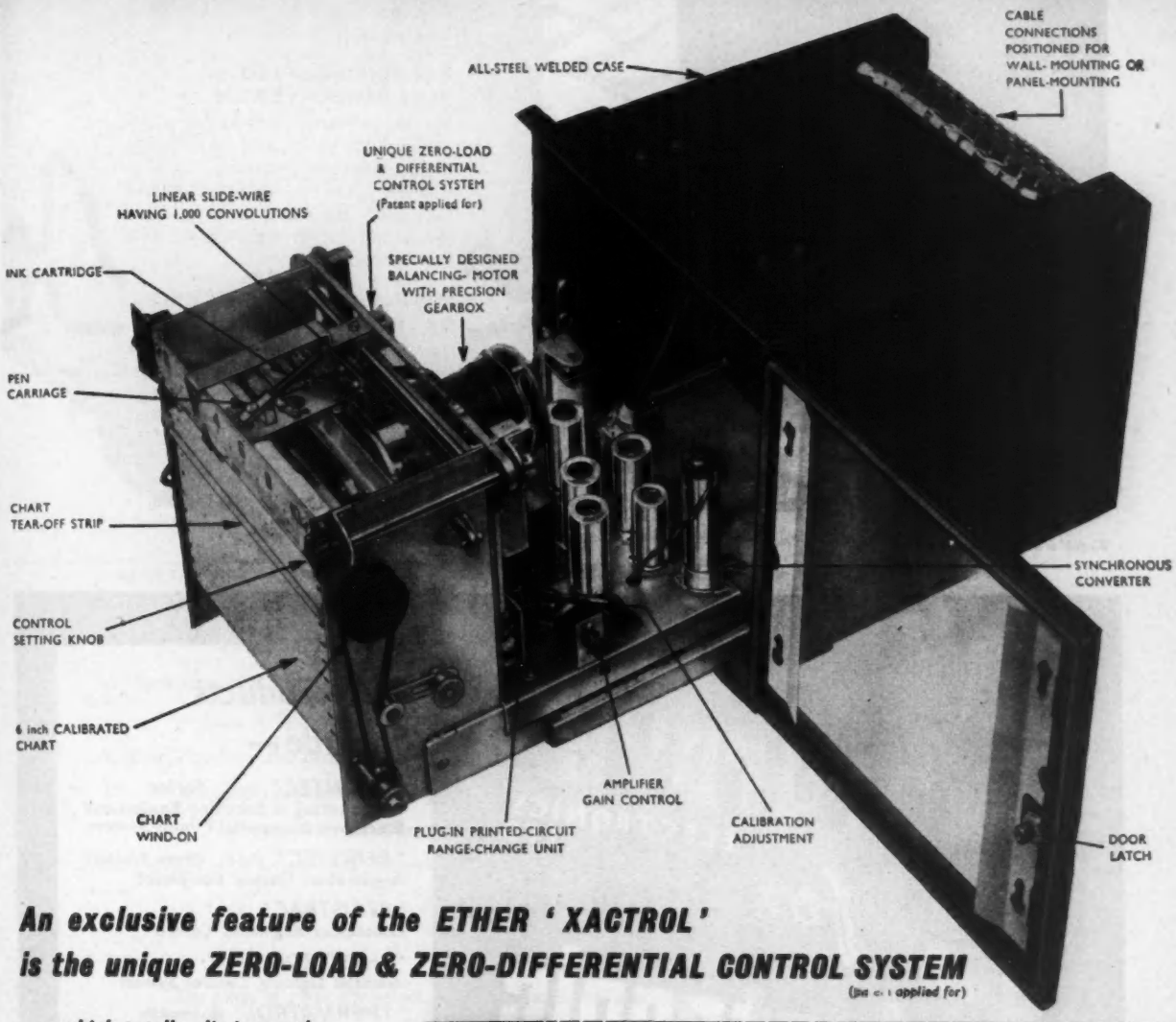

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(Patent applied for)

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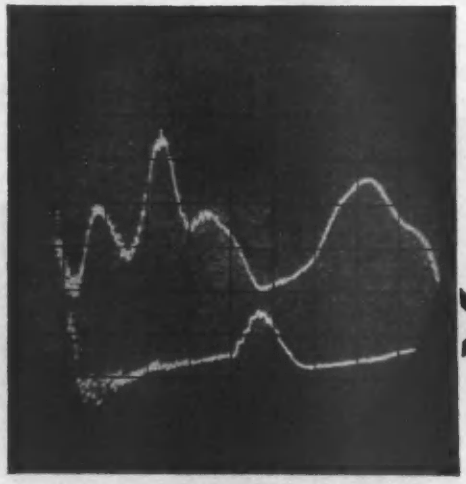
TWO POPULAR PHOTO-RECORDING MATERIALS



You want clear records, so you use a photographic emulsion particularly sensitive to the colour of the trace. And you want a practical combination of emulsion speed and colour sensitivity. Kodak make a wide range of materials for photo-recording so you can have what you want. Here are details of two of them.

R.20 MEDIUM-SPEED BLUE-SENSITIVE FILM

For use in instruments having slow-moving light spots, and for cathode-ray oscilloscope recording with blue screens. It has very high contrast and resolution. Sensitive to all sources except those with mainly green and red emission.

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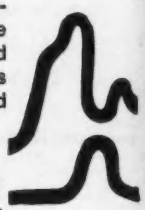
Recommended for recording work which involves the highest speeds, especially where screens are used with very high writing speeds. Sensitive to ultra-violet and to the visible spectrum.



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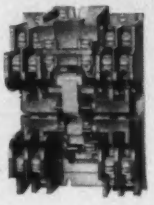
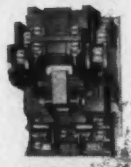


8-pole Open Style
with one auxiliary
contact added.



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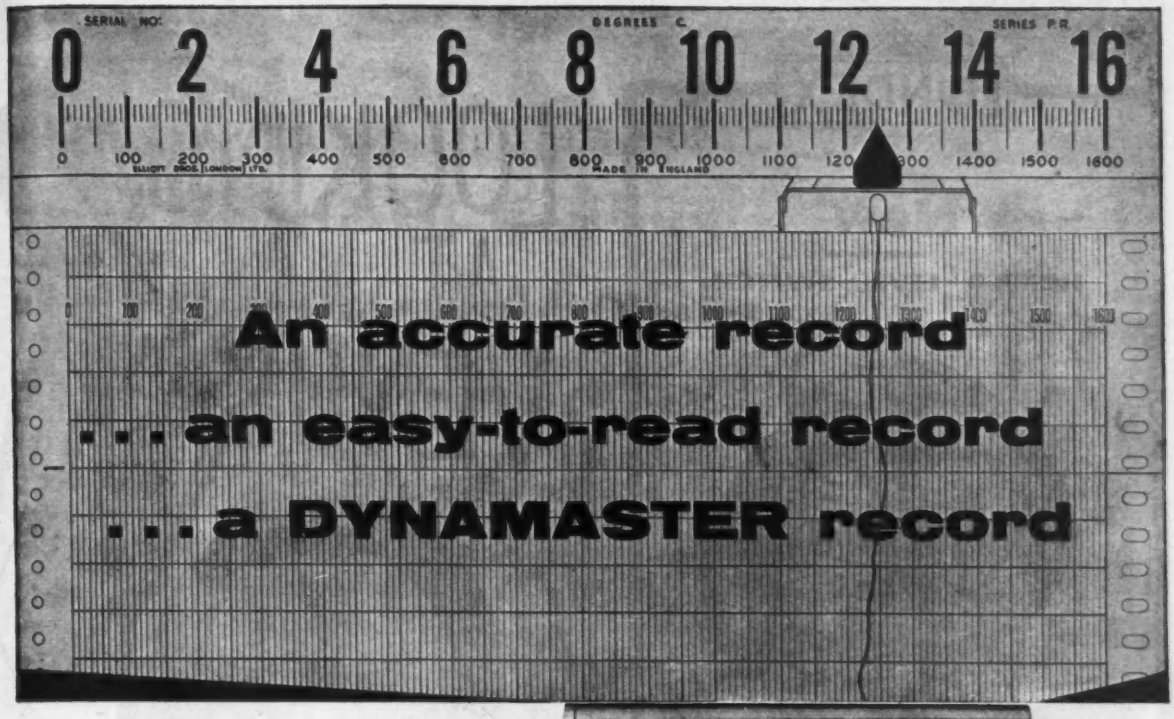

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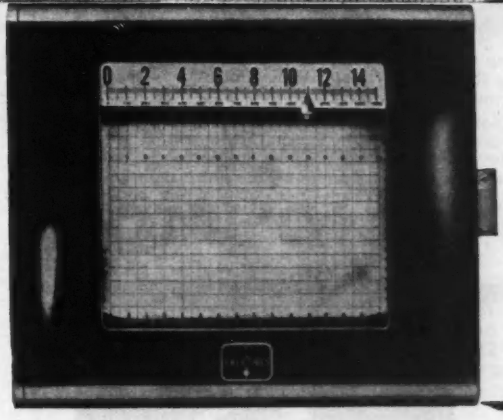

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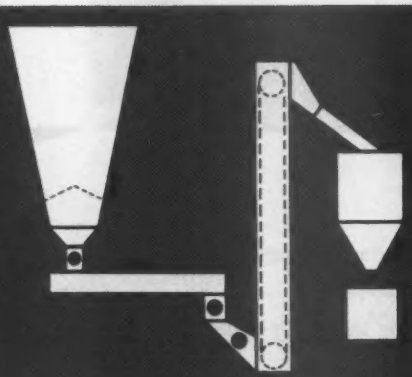

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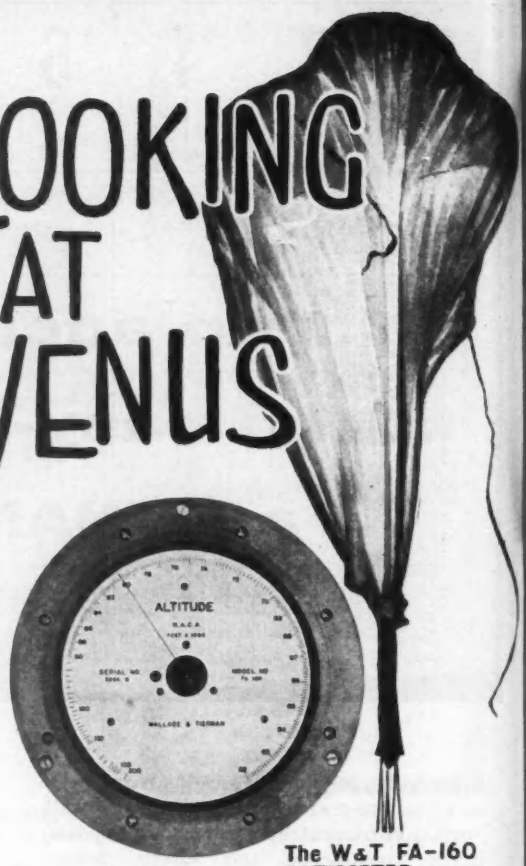

The W&T FA-160 ALTIMETER

Last year, the United States Navy carried out a balloon project to photograph the planet Venus. Amongst the instruments used for recording information was a W & T Absolute Pressure Indicator type FA-160 which records heights of over 80,000 feet. This Altimeter weighs only three pounds. In the balloon project, it provided accurate readings at rates of descent up to 4,000 feet per minute —readings that were checked by ground radar.

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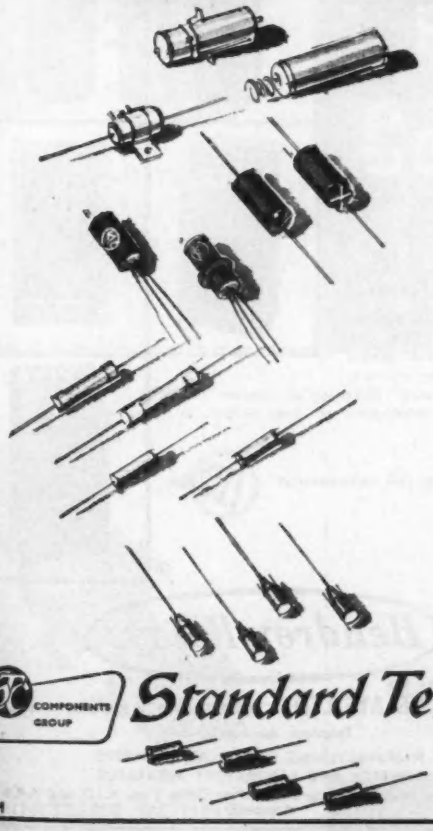

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Get to know about STC Components—write for booklet M/103 which lists all components and their relevant technical literature.

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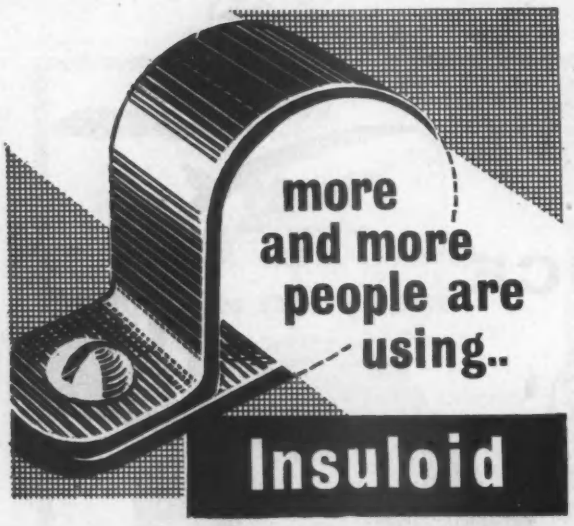

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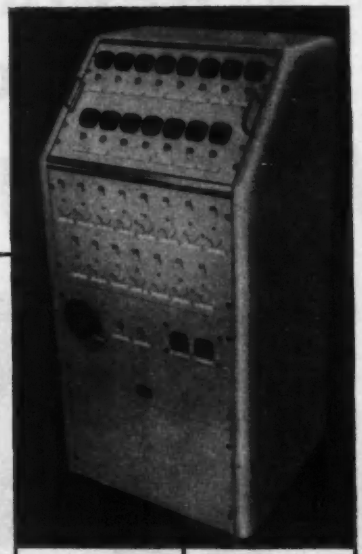
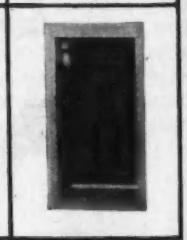
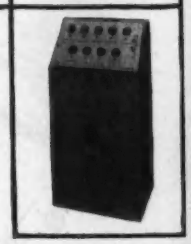
HENDREY

Control Consoles







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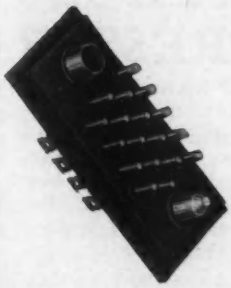

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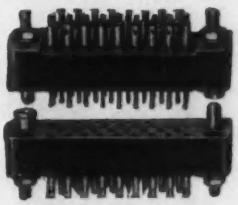

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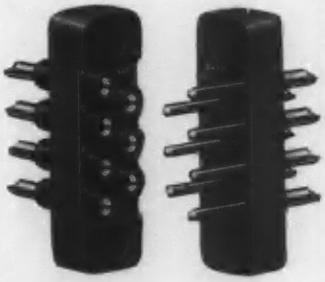

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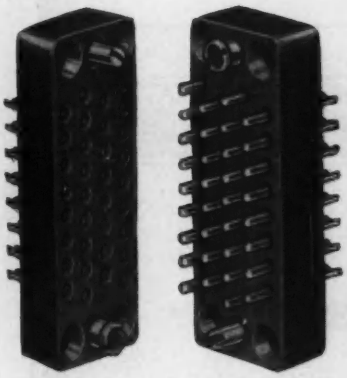

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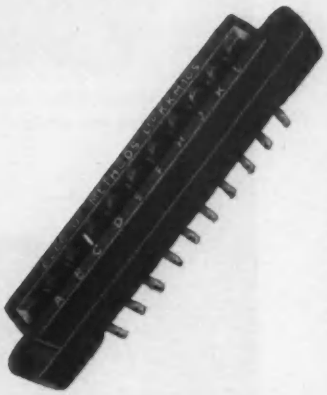

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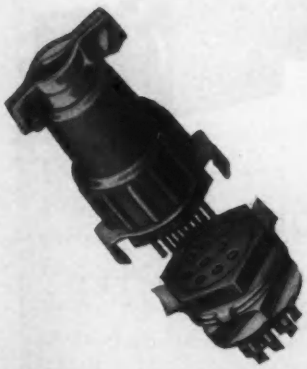

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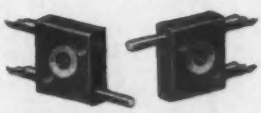

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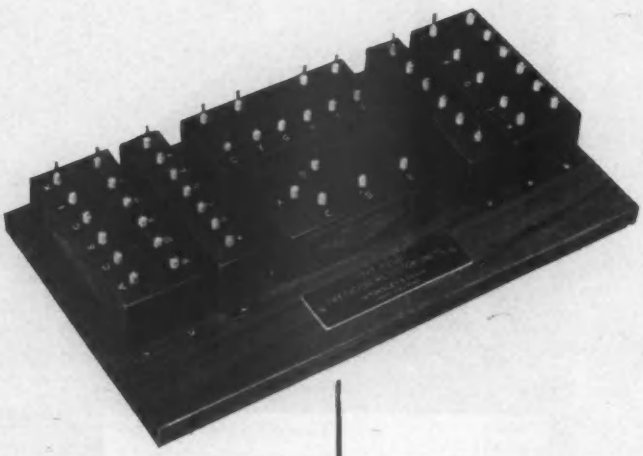

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2"-2½" 3½" & 5"

new Type R

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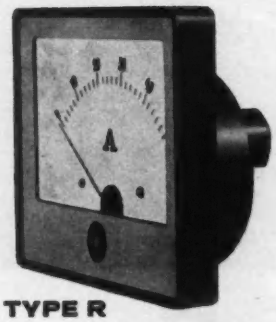

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2" TYPE R

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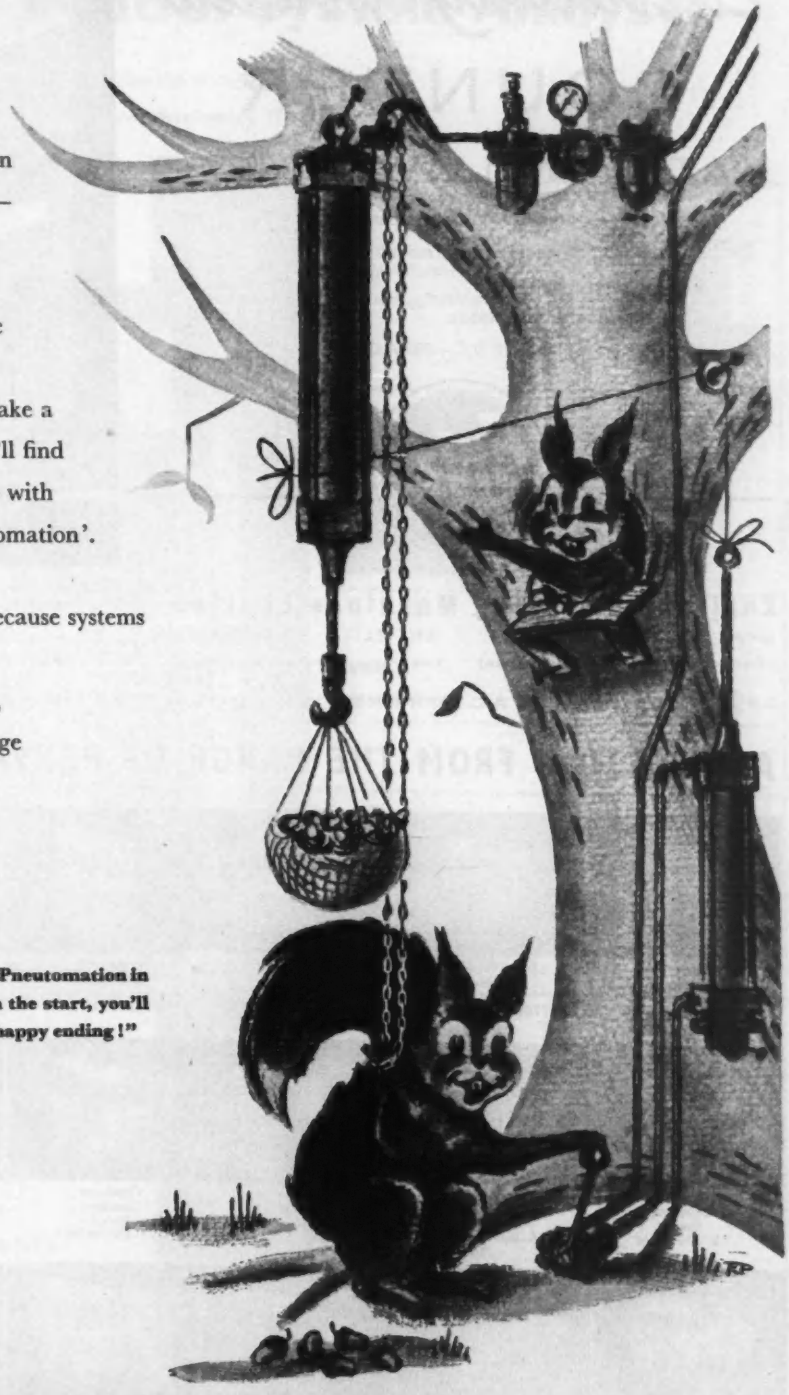

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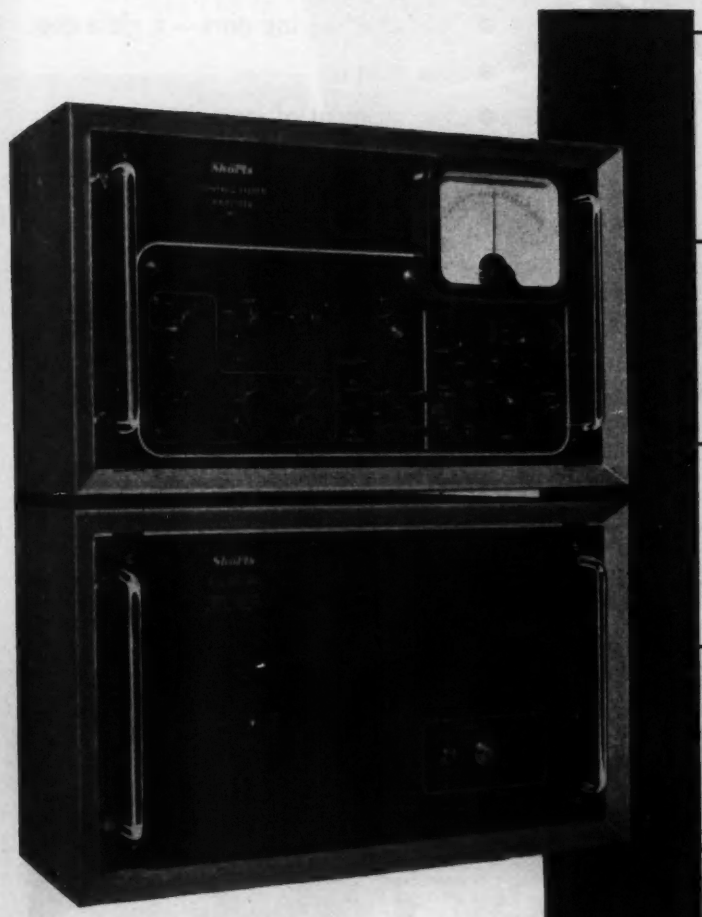

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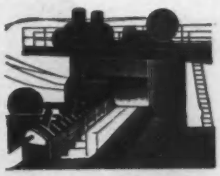
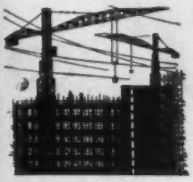
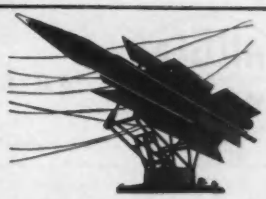
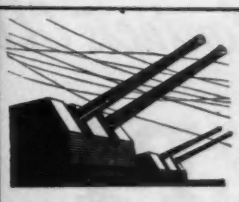




Design of heavy crane control gear

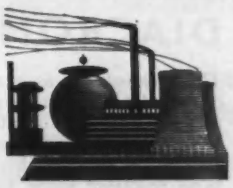
Missile servo analysis





Gun control problems

Reactor control mechanisms



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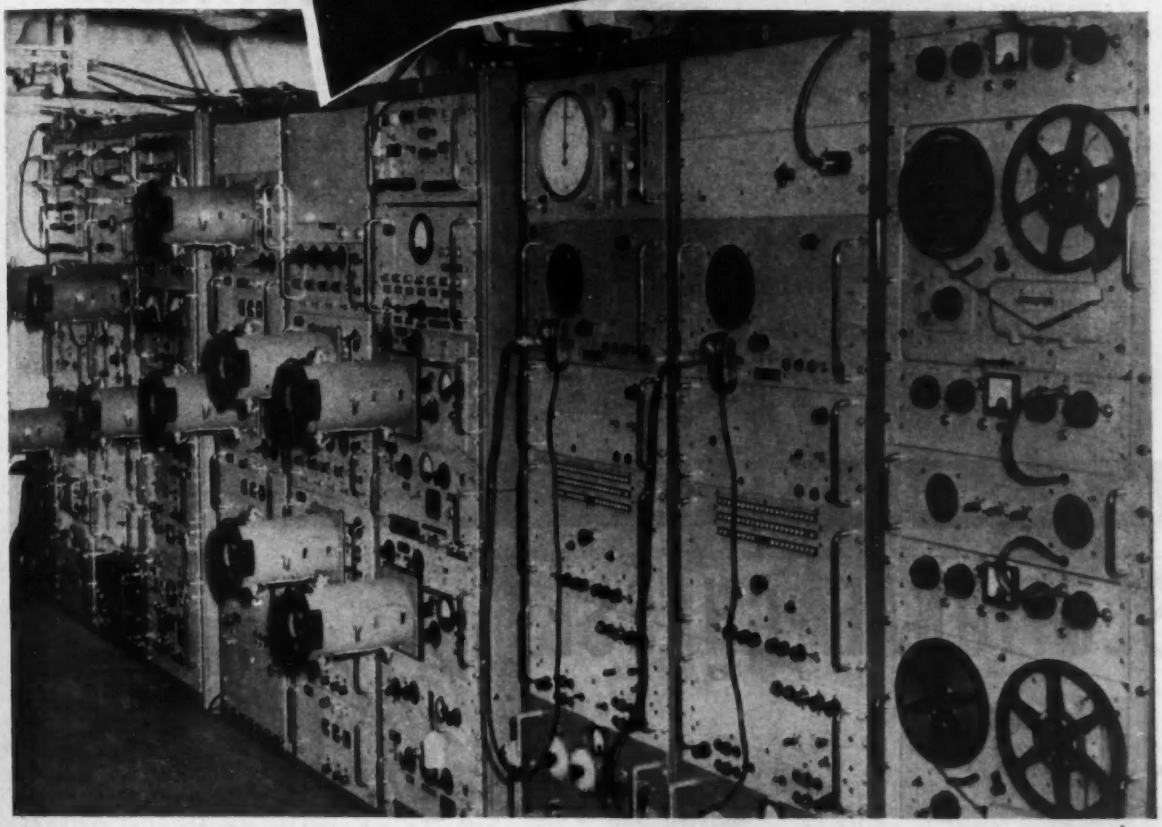

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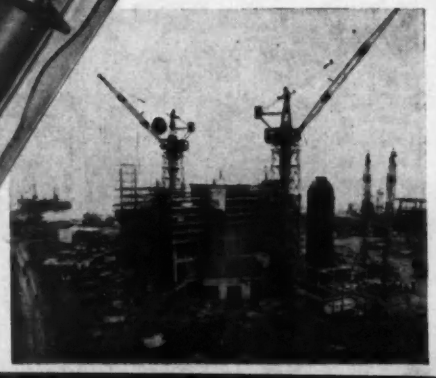

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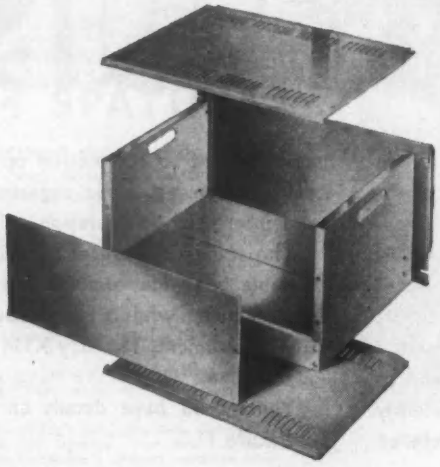

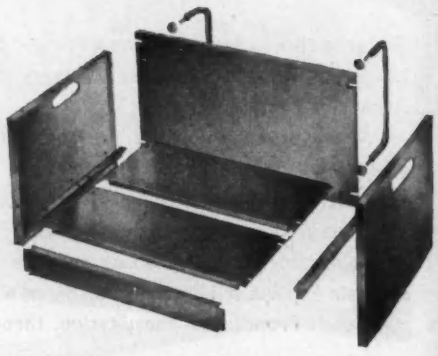

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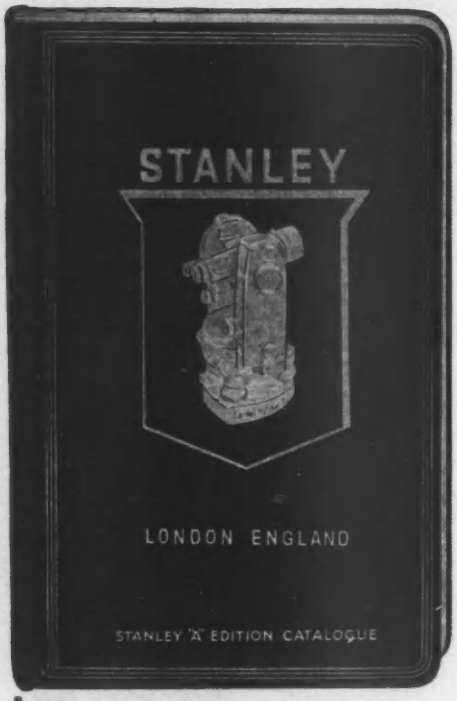

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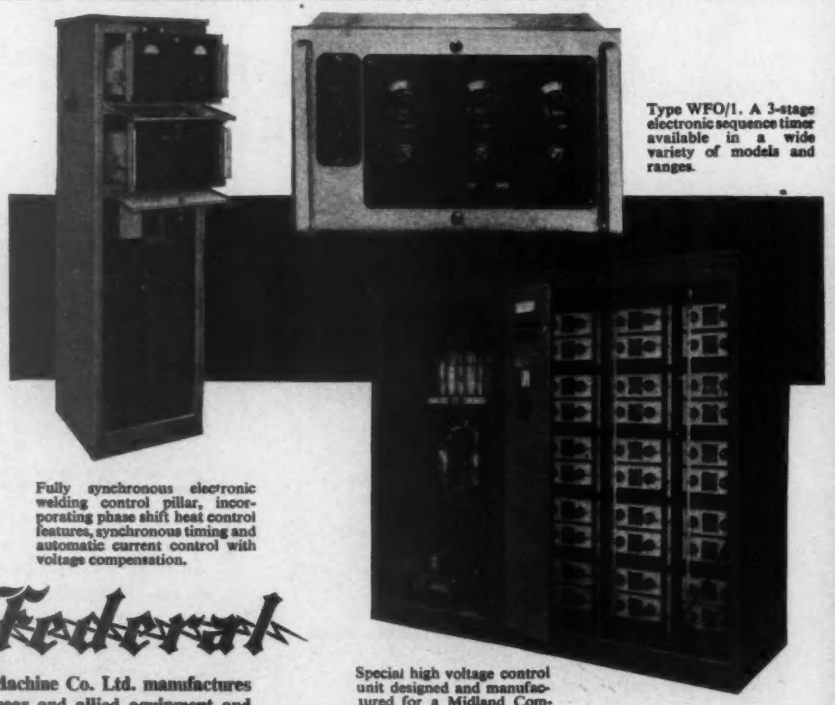

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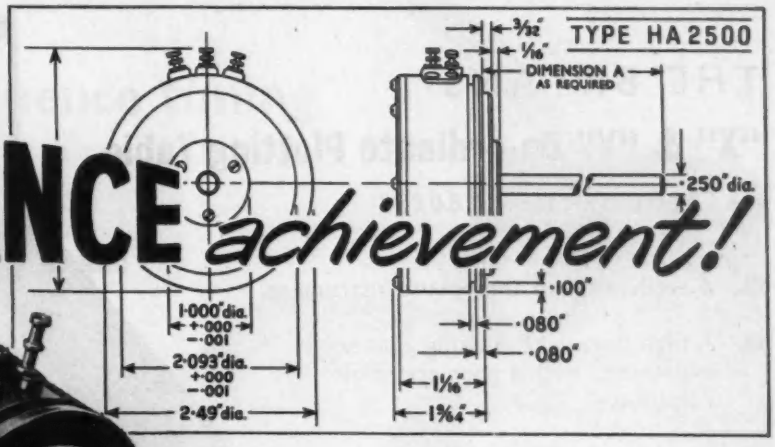
a New RELIANCE *achievement!*



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TYPE **HA 2500**

HIGH LAW ACCURACY
without cam correction

In this new continuous rotation type HA 2500 Potentiometer intensive research has made possible high accuracy with much improved mechanical stability. A precision machined light alloy body, an accurately ground ball-bearing mounted spindle – a patented design that eliminates cam correction, combine to give the following advantages :—

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Resistance range	100 to 100,000 ohms.
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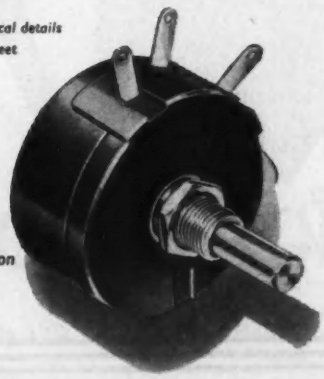
The **TYPE W3** (3 WATT)

This model conforms with specification DEF-5121 style RVW 7 & 8 (formerly RAC.RAD) and is a fully sealed unit with integrally constructed moulded cover. Also available in unsealed version.

Full technical details in Data Sheet No. 9



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- A well-designed and robust instrument.
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Elcontrol Timers for process and machine control include:-

PROCESS TIMERS

which start a process on closing the initiating switch, and stop it at the end of the time interval.

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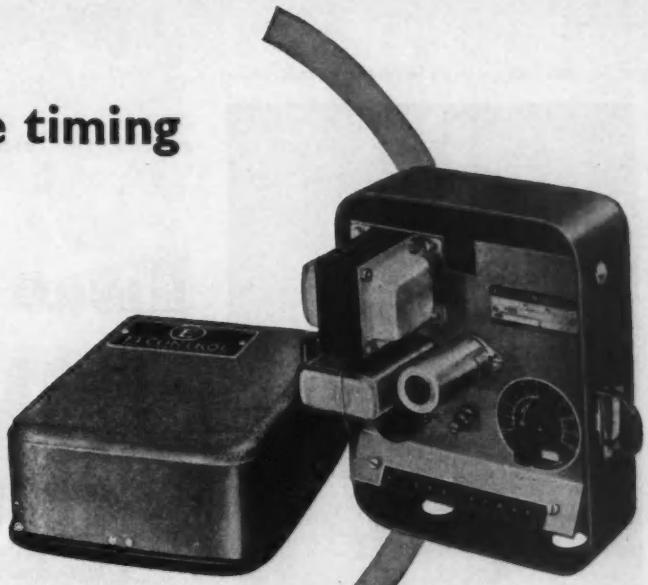
which start or stop a process at the end of the time interval.

CYCLIC TIMERS

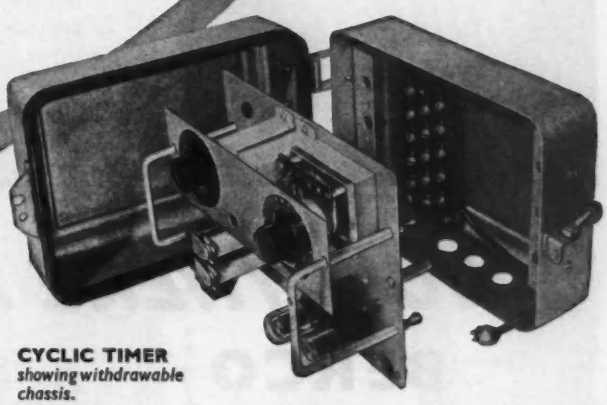
which automatically repeat a process at pre-determined intervals.

SEQUENCE TIMERS

which give full programming of complex processes embodying a number of timing stages.

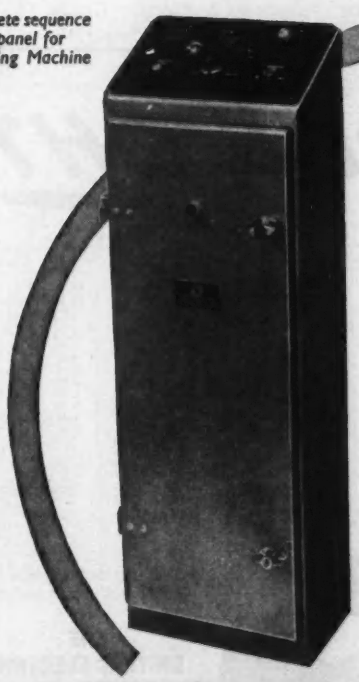


The new **TRU3 TIMER** *or Delay Switch £14.*



CYCLIC TIMER *showing withdrawable chassis.*

A complete sequence control panel for Diecasting Machine control.



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Standard Timing Ranges cover between them 0.1 to 300 seconds.

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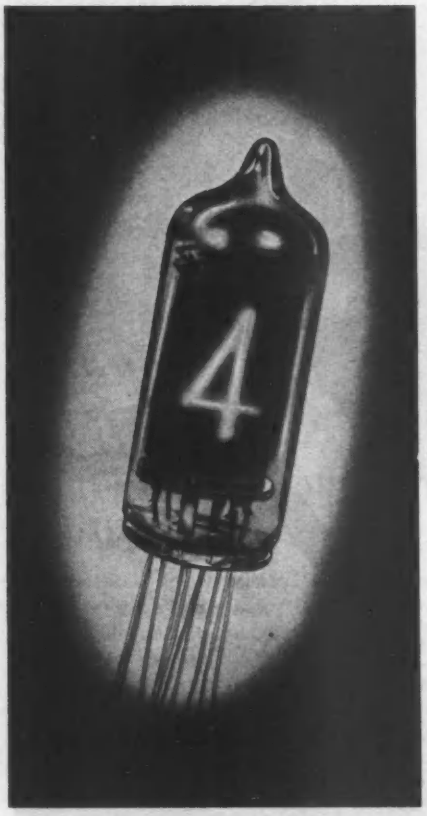

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a high quality miniature, in-line, digital display tube.

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P.N.2

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- MAXIMUM ELECTRICAL PERFORMANCE
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- CAN BE USED IN TROPICAL SITUATIONS WITHOUT MODIFICATION

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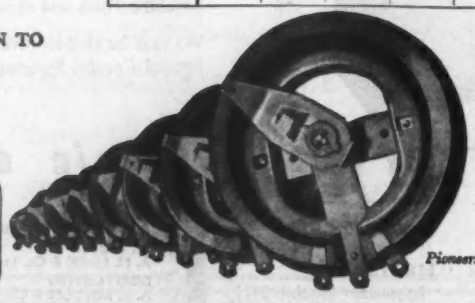
1	—	7.07	8.66	10.00	12.50	15.0	17.3	22.3
2	3.54	5.00	6.12	7.07	8.66	10.6	12.2	15.8
3	2.89	4.08	5.00	5.75	7.07	8.66	10.0	12.9
5	2.24	3.16	3.88	4.77	5.48	6.71	7.75	10.0
7.5	1.82	2.58	3.16	3.65	4.47	5.48	6.32	8.17
10	1.58	2.24	2.74	3.16	3.88	4.74	5.48	7.07
15	1.29	1.83	2.24	2.58	3.16	3.87	4.47	5.78
25	1.00	1.41	1.73	2.00	2.45	3.00	3.46	4.47
50	.707	1.00	1.23	1.41	1.73	2.12	2.45	3.16
75	.578	.818	1.00	1.15	1.41	1.73	2.00	2.58
100	.500	.707	.866	1.00	1.23	1.50	1.73	2.23
150	.408	.575	.707	.818	1.00	1.22	1.41	1.82
200	.354	.500	.612	.707	.866	1.06	1.22	1.58
350	.268	.378	.463	.535	.655	.803	.926	1.19
500	.224	.316	.388	.447	.548	.671	.775	1.00
1,000	.158	.224	.274	.316	.388	.474	.548	0.708
1,500	.129	.183	.224	.258	.316	.387	.447	.578
2,500	.100	.141	.173	.200	.245	.300	.346	.448
5,000	—	.100	.123	.141	.173	.213	.245	.315
7,500	—	.081	.100	.115	.141	.173	.200	.258
10,000	—	—	—	.110	.125	—	.173	.224
15,000	—	—	—	—	—	—	—	.183



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Pioneers of the toriodally wound rheostats in England.

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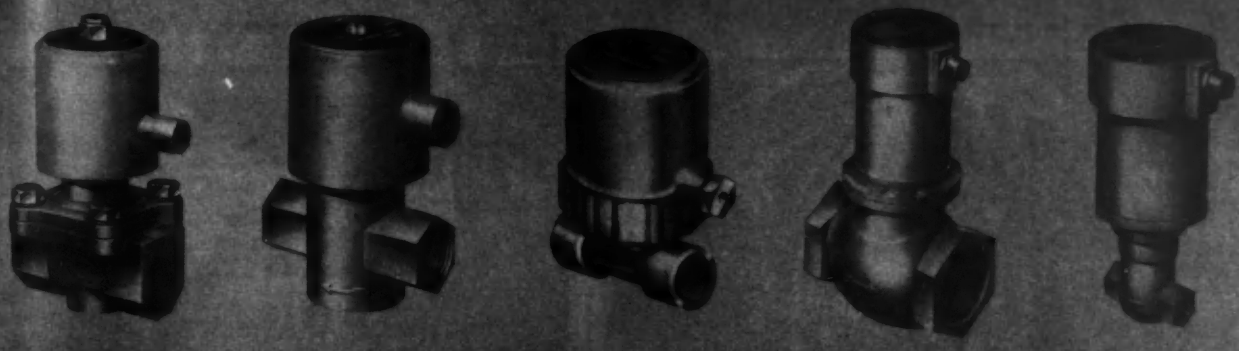

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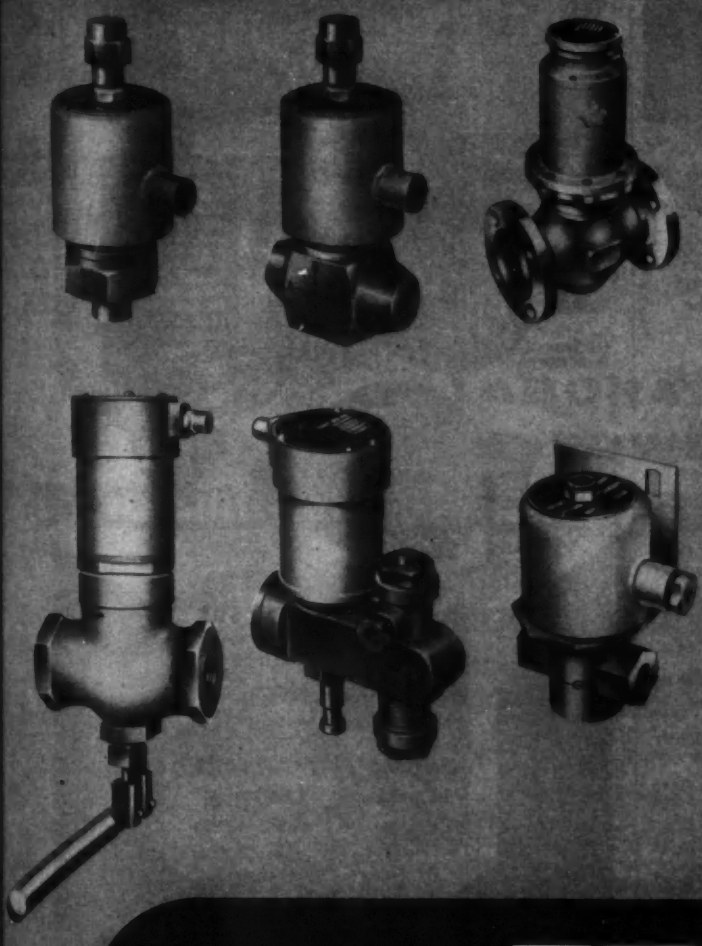

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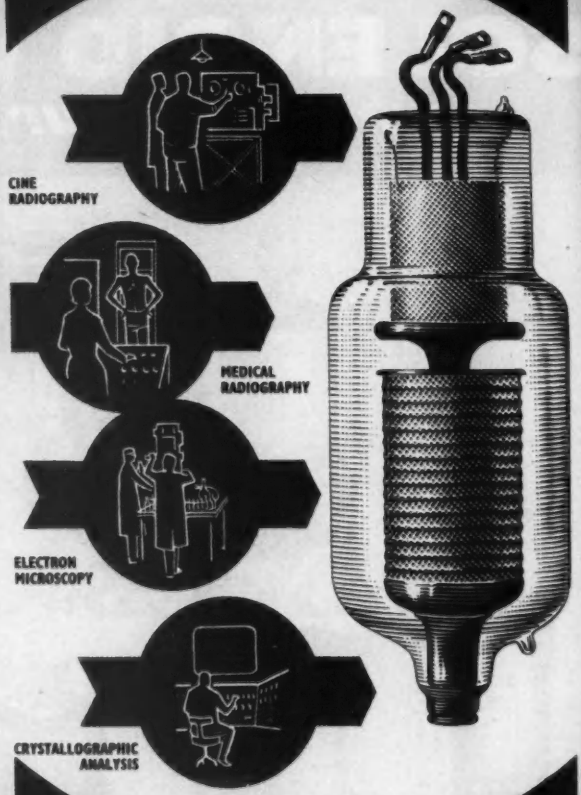

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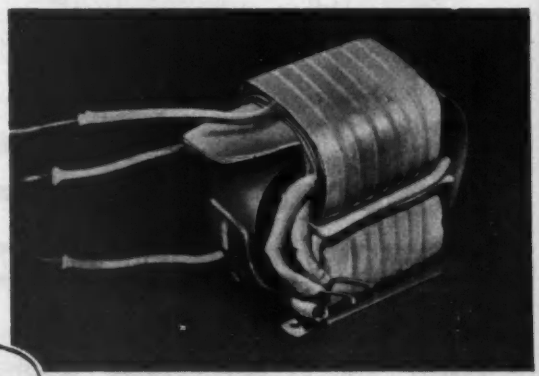

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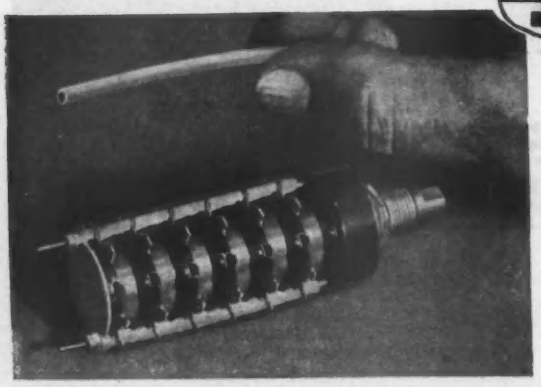

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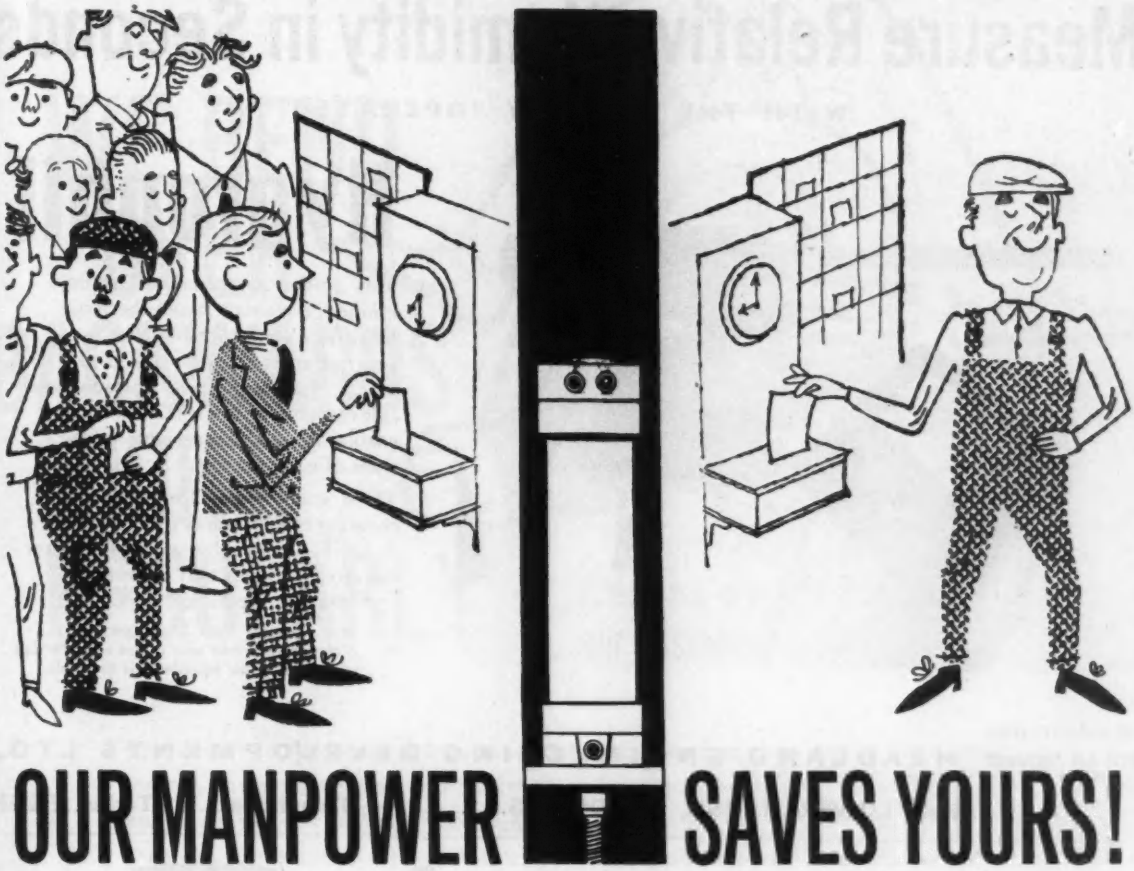

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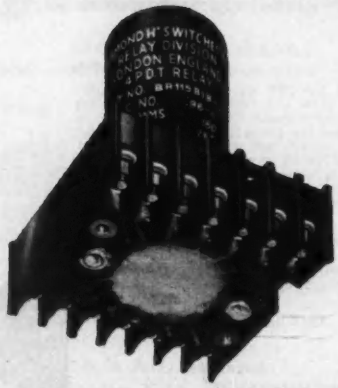

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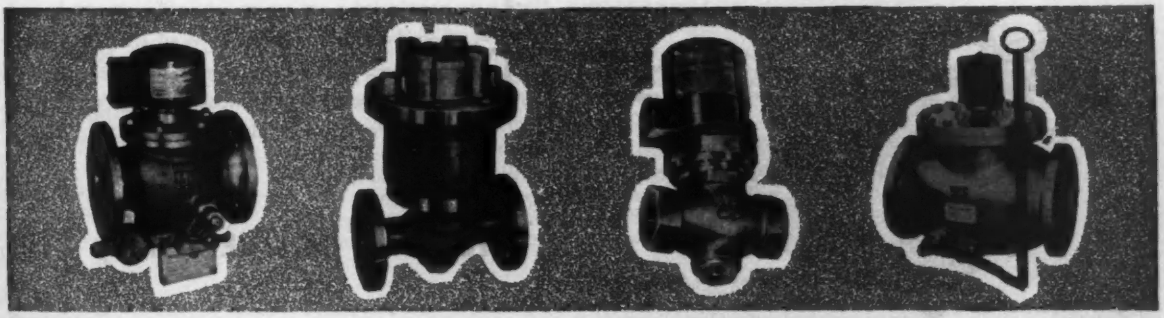

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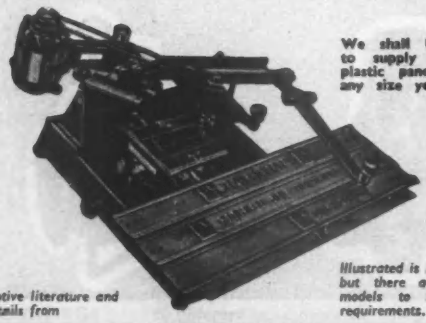

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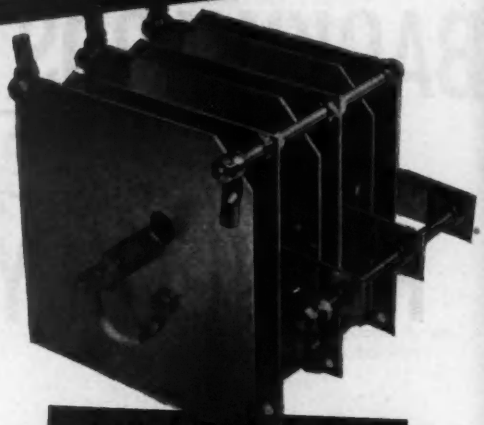

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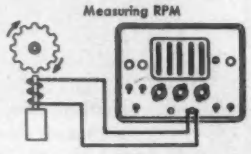

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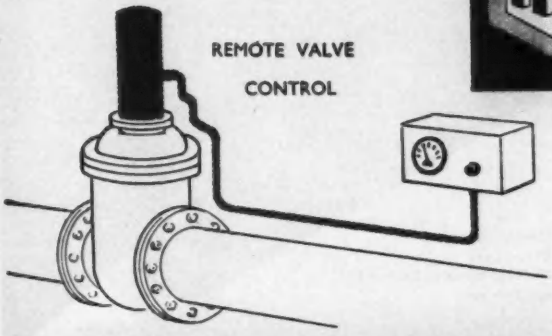

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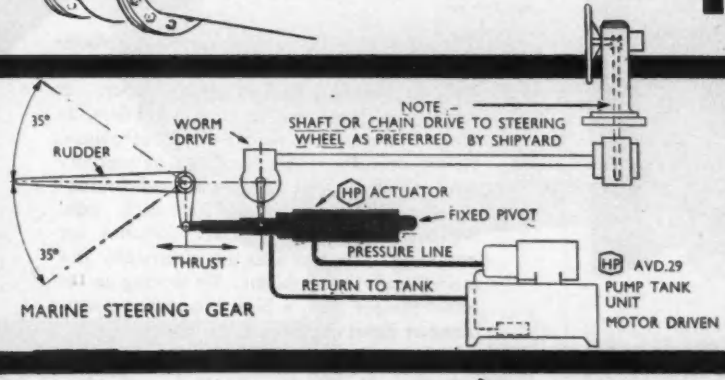

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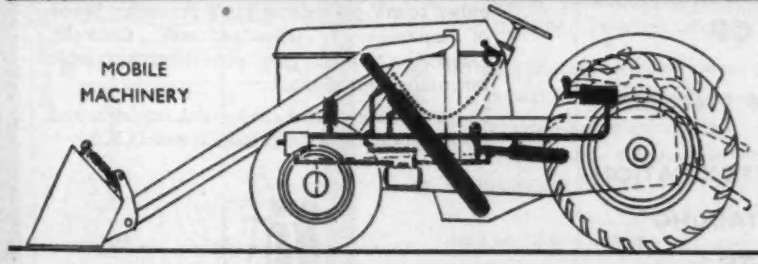

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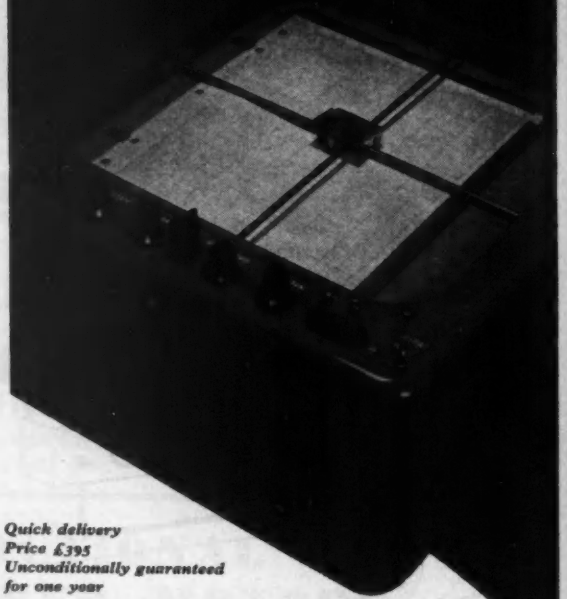

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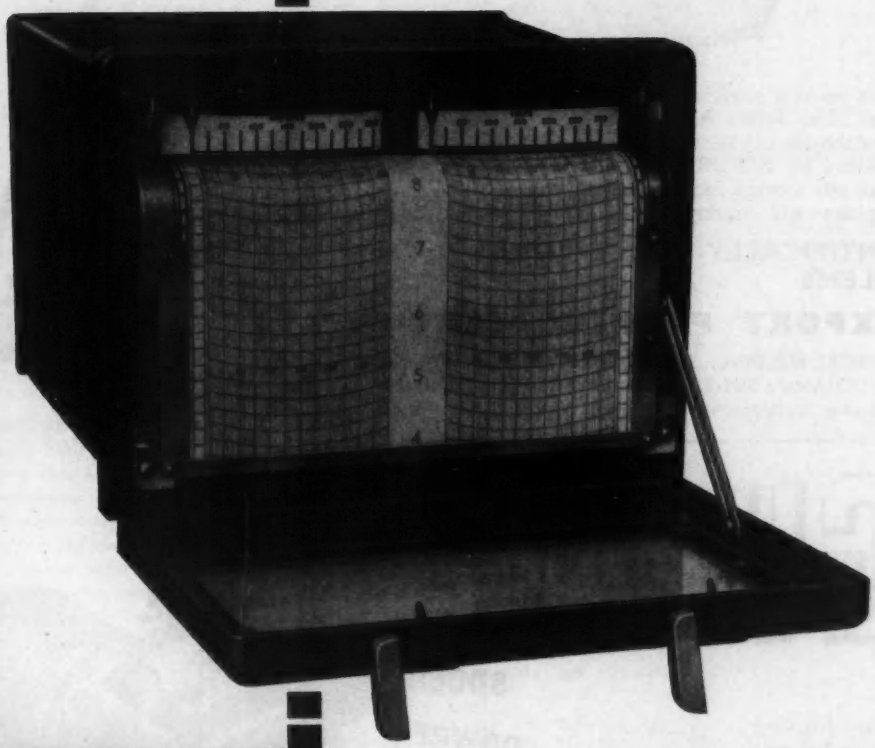

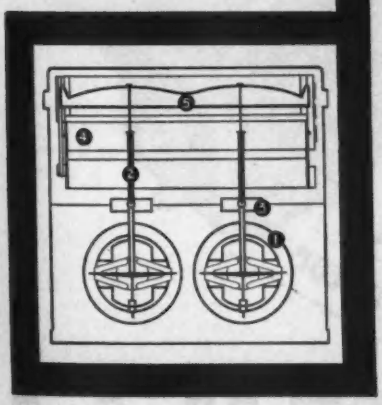

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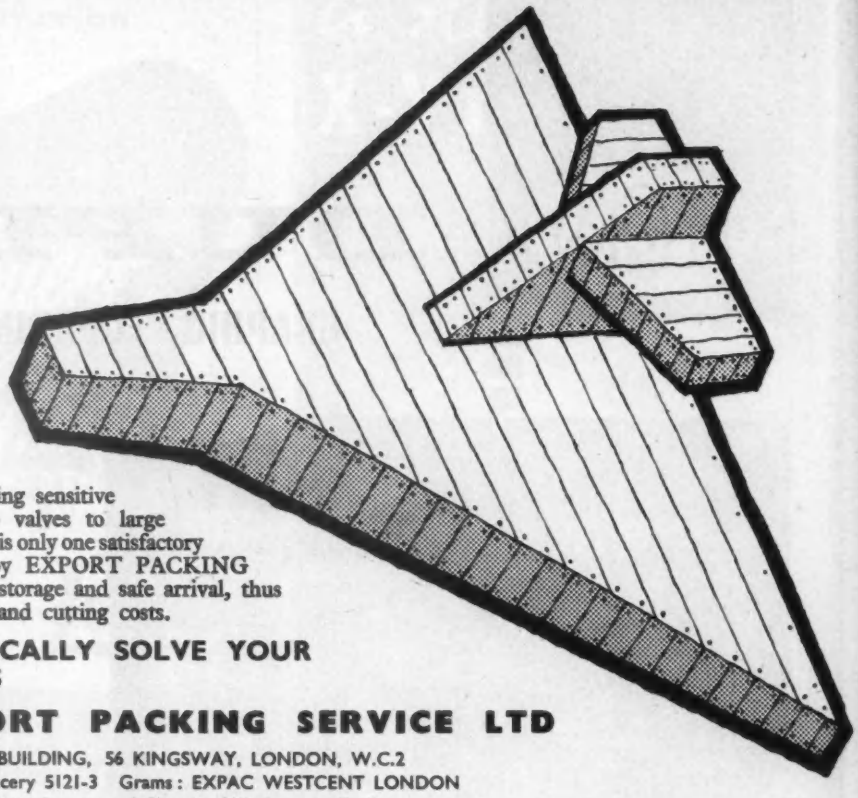

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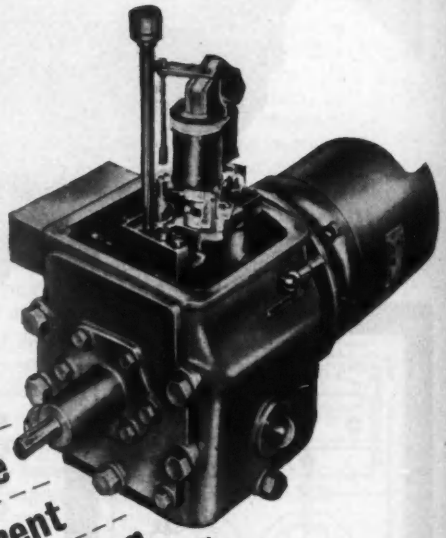

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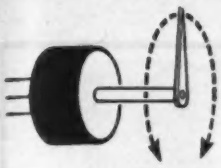
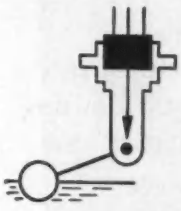
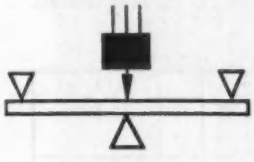


Angular Position

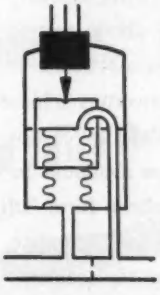


Fluid Level



Force

Linear Position



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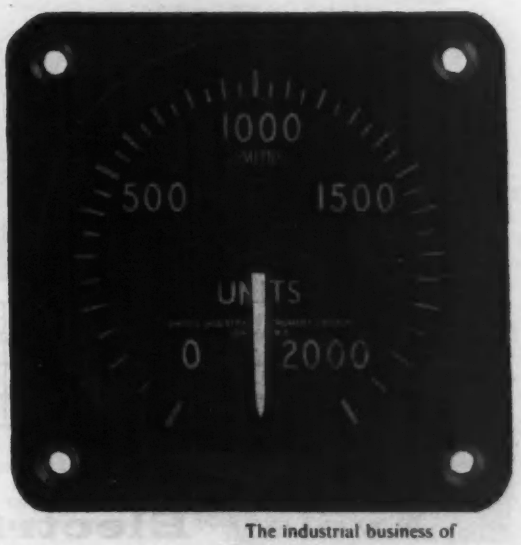
In terms of remote indication, the name SMITHS means a vast and comprehensive range of instruments of "stand-anything, go-anywhere" robustness.
For example:—

SMITHS "DESYNN" SYSTEM OF REMOTE INDICATION
is a simple, robust and extremely accurate method of transmitting to a remote observation point such functional information as Angular Position, Fluid Level, Force, Linear Position, Differential Pressure and Pressure.

- Operates from either 12 or 24 volt D.C. supplies
- Flameproof and watertight versions available
- Two or three Indicators can operate from one Transmitter
- Single or Multi-Channel Recorders are also available for use with this system

A POINT WORTH NOTING
All Smiths Instruments are backed by a comprehensive after-sales service



A typical 4" watertight square flange mounting 'Desynn' indicator with a novel form of prismatic illumination

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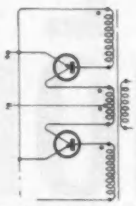

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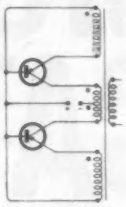
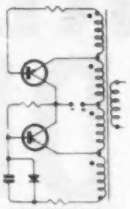


COMMON EMITTER



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Bridge circuits, voltage doubler circuits, tripler and full-wave circuits can be used in the H/T secondary.

Type		Power
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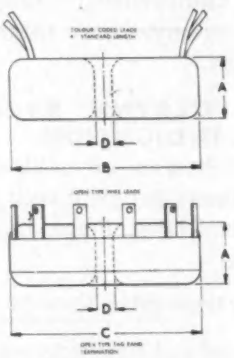
T/5B6/300/2T	...	5–15
T/5AC6/300/2T	...	15–45
T/3B12/300/2T	...	2–5
T/5B12/300/2T	...	5–15
T/5AC12/300/2T	...	15–45
T/25C12/300/2T	...	45–75
T/3B24/300/2T	...	2–5
T/5B24/300/2T	...	5–15
T/5AC24/300/2T	...	15–45
T/25C24/300/2T	...	45–75
T/6AD24/300/2T	...	75–120
T/26D24/300/2T	...	120–150



The use of AVEL TOROIDS gives higher efficiency in DC-DC Converters. Wide bandwidth and HCR alloy core ensures fast switching (approx. 3 microsecs.) with negligible overshoot yielding efficiencies of 75–92% overall.

WATTS Power Rating	A	B	C	D
2–5	¾	1½	1⅝	2BA Min. Clear.
5–15	¾	2	2¼	,, ,,
15–45	1¼	2	2¼	OBA ,,
45–75	1¼	2	2¼	,, ,,
75–120	1½	2½	2⅝	,, ,,
120–150	1⅝	2½	2⅝	,, ,,

DC - DC converters

★ Smaller 2½" × 2½" × 3⅛"
★ More efficient 84% at 30W
★ Less noise
★ Less ripple
★ Better made

Built in aluminium castings, with fire-glass insulation, silicon rectifiers and tropical rating components throughout, these converters achieve peak performance at modest cost by good design—and are available on short delivery in skeleton form (left) or in screening cases with complete protection for use as replacements for generators and vibrator packs. Standard types give 300 volts DC output with taps for 250 and 200 volts.

Type	3B6	5B6	5AC6	3B12	5B12	5AC12	25C12	3B24	5B24	5AC24	25C24
Input, Volts	6	6	6	12	12	12	12	24	24	24	24
Max. Watts	5	15	45	5	15	45	75	5	15	45	75
List Price	£10 8s.	£10 14s.	£11 16s.	£10 8s.	£10 14s.	£11 16s.	£12 4s.	£11	£11 8s.	£12 8s.	£12 14s.

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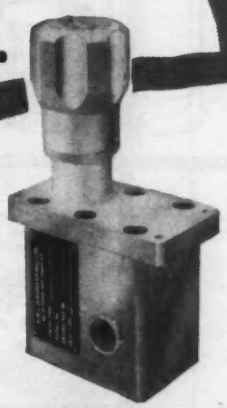

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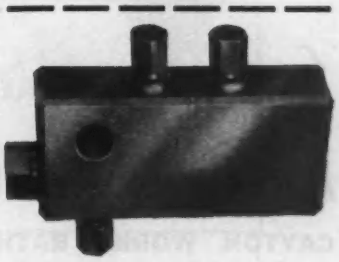

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* ELECTRICAL EQUIPMENT
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and a host of subsidiary industries

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In all grades, in cut pieces or precision stamped to ultra close tolerances. Valve bridges. Lamp baffle plates. Capacitor micas. Heater elements (wound and tagged), washers, strips.

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In sheets, rods and tubes. In all commercial and type approved grades of paper and cotton base. Extensive stocks allow for immediate delivery in most cases. Also supplied in strips and panels to close tolerances. Copper clad laminates for the Radio industry.

CONTAINERS The well known Delanco vulcanized fibre containers have a place in practically every industry. Made to your own specification or supplied as types developed for special purposes.
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High heat components moulded to spec. with or without inserts. In materials to withstand working temperatures of 250°c. *Send for Technical Folder.*

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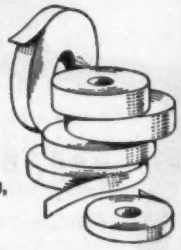

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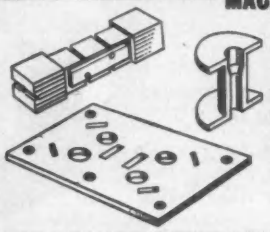
In all Delanco materials, Bakelite Vulcanized Fibres, Leatheroid, Glass Fibre, Ebonite, Presspahn. All tools made in our own modern and extensive tool rooms, from up to the minute equipment.



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Delanco Bakelite tube, paper or cotton base is used in all industries, with a high percentage in the radio and communications field. Square and rectangular. In 48" lengths, or cut to spec, and can be pierced slotted and grooved. Super High gloss finish in addition to standard finish, can be supplied.

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Suitable for

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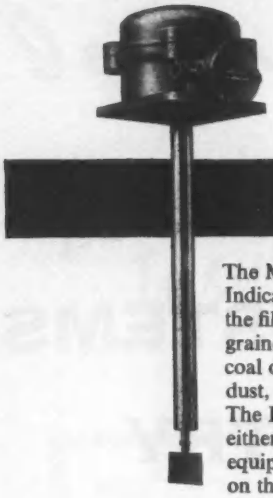

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ELECTROLUBE lubricants are a British discovery—a scientific preparation—not "just another switch cleaner".

ELECTROLUBE lubricants stay effective for months.

Make contact with *Electrolube* BRAND LUBRICANT

ELECTROLUBE Brand No. 1 for light current applications, reduces fixed and relay contact resistance, stops audio interference, increases h.f. and l.f. gain by 3 dB etc.

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Available in New NYLON SNORKEL Container

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Size Range 10 B.A. to ¼" B.S.F.

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15 grm. cm.

6" Contact-Making Indicator

This exceptionally high torque instrument can be supplied for D.C. and A.C. rectifier operation, with high and low contacts (100mA, 50 volts D.C. or non-inductive A.C.).

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Self-acting flow controller (volume governor) for small gas flows at pressures between 1 and 10 p.s.i.

Factory Calibrated to control the flow to within 2% of the desired rate irrespective of pressure changes.

¼" B.S.P. female connections, for in-line mounting.

Flow Range: 0·1-100 c.f.h. Air.

Price £6.

This simple instrument requires no outside power supply, and needs no attention in service.

For application to Burners where back pressure variations disturb the fuel gas-air ratio.

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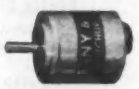

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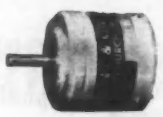

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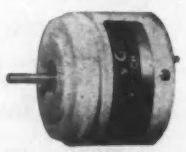

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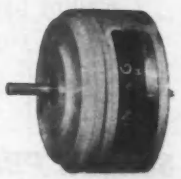

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GENERAL DATA

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100 ohms. to 100 K ohms.

MECHANICAL RANGE
360 degrees or with stops

ELECTRICAL RANGE
355 degrees or greater

TORQUE
0·025 oz. ins. to 0·25 oz. ins. Depending on Type

All items have low inertia, precision ballraces, aluminium alloy cases and are suitable for operation over an ambient temperature range: minus 50°C to plus 150°C. All Potentiometers are fitted with rear connections—either solder pins or captive leads.

SINGLE AND MULTI-GANGED UNITS.

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"CORREX" TENSION GAUGES

The only instrument solely designed for accurately measuring tension on *Relays*, *Contacts*, *Switchgear*, and electrical apparatus of all kinds. Gauge measures in grammes, and a large range of sizes is produced to cover from 0.3–2,000 grammes.
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ADCOLA

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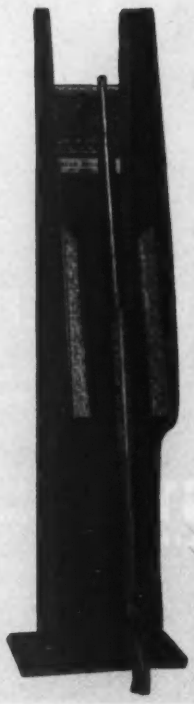

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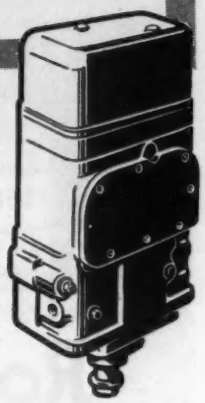

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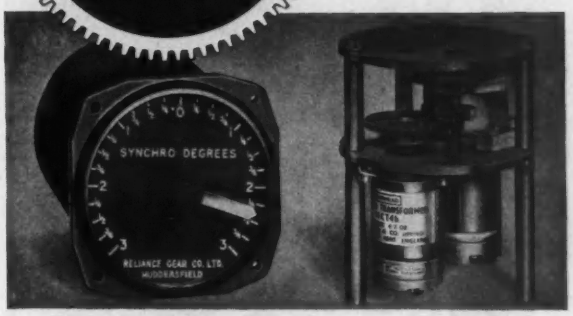

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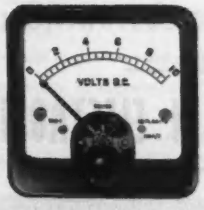

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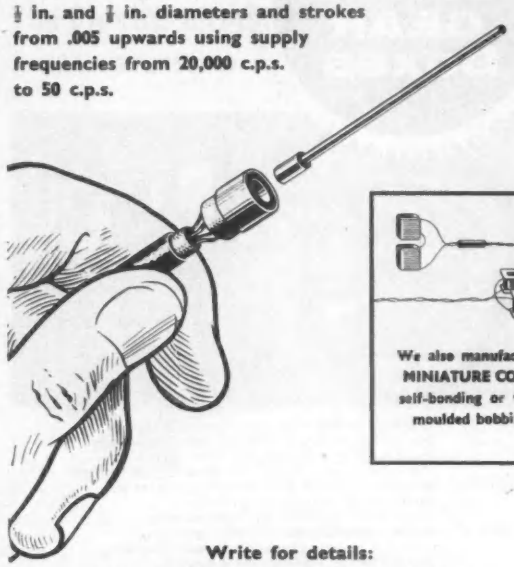

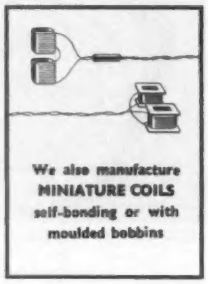

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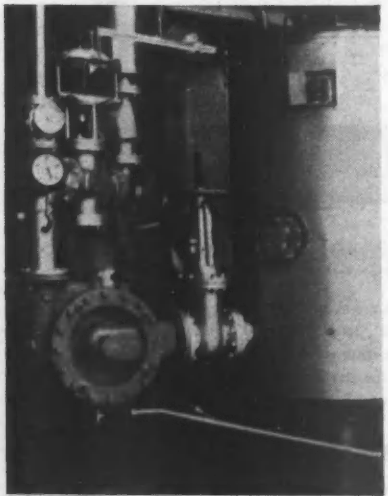

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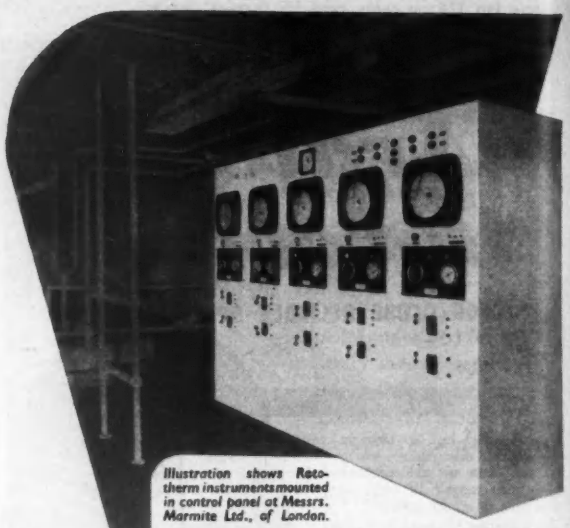

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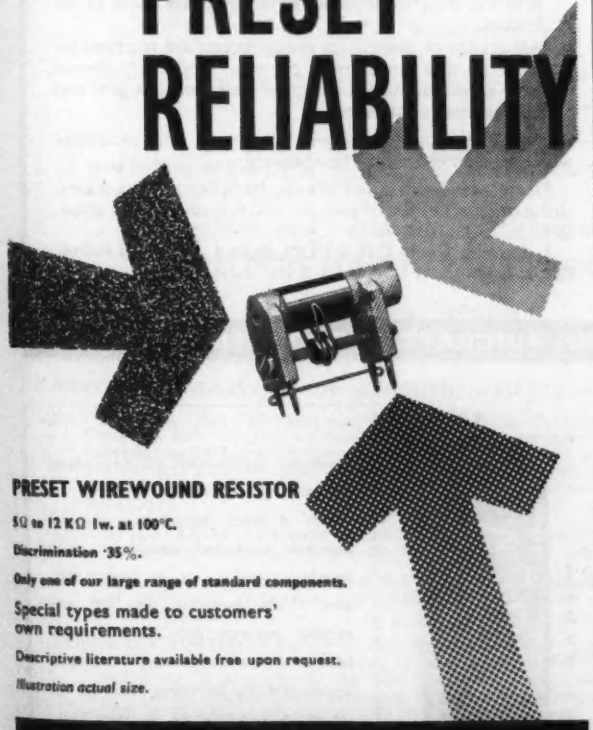

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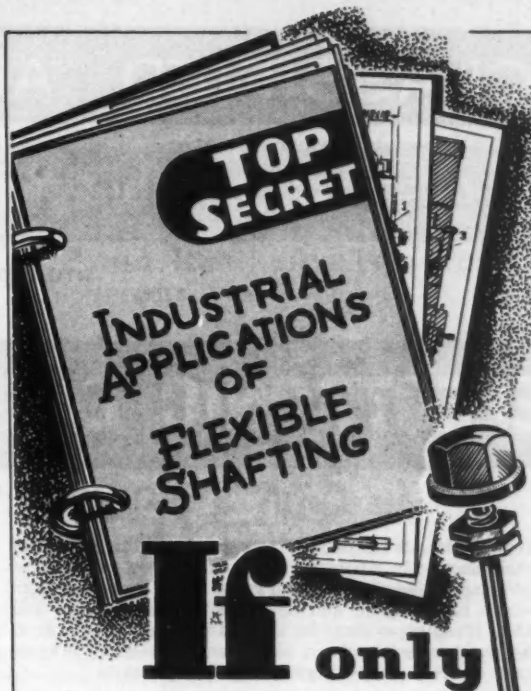

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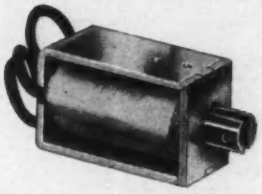

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